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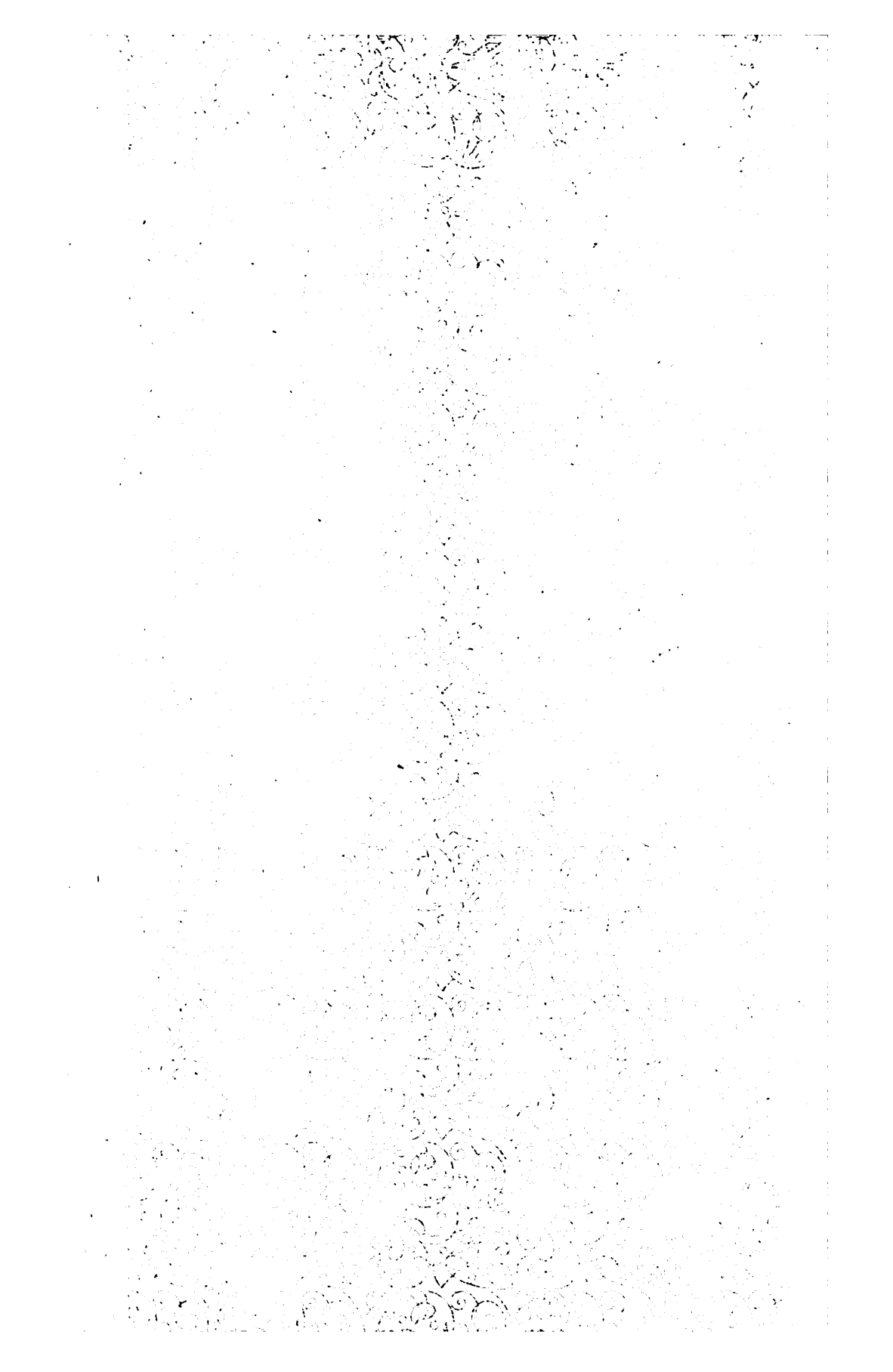

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Fred Tibbetts
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MAR 27 1914

REPORT

ON

PROPOSED WATER SUPPLY

FOR THE

Richmond Municipal Water District

TO THE

HONORABLE BOARD OF DIRECTORS

OF THE

RICHMOND MUNICIPAL WATER DISTRICT

RICHMOND, CALIFORNIA

HAVILAND, DOZIER & TIBBETTS

CIVIL ENGINEERS

San Francisco - Oakland - Sacramento

CALIFORNIA

Report on Proposed Water Supply

for the

Richmond Municipal Water District

to the

Honorable Board of Directors

of the

Richmond Municipal Water District

UNIV. OF CALIFORNIA

HAVILAND, DOZIER & TIBBETTS
CIVIL ENGINEERS
SAN FRANCISCO, OAKLAND, SACRAMENTO

DECEMBER, 1913
No. 5644

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UNIV. OF
CALIFORNIA

PUMPING PLANT

276053

Directors, Engineers and Newspaper Men on Wharf at Toland's Landing,
near Intake Pumping Plant

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LETTER
OF
TRANSMITTAL

Letter of Transmittal

To the Honorable Board of Directors of the Richmond Municipal Water District, Richmond, California.

GENTLEMEN: This report is submitted in accordance with your general instructions to make a preliminary investigation and report upon all available sources of water supply for the Richmond Municipal Water District, together with the necessary distribution system and the extent, if any, to which present water systems could be profitably utilized.

SCOPE OF REPORT.

In order that the information concerning this project herein contained may be complete, there is included in the body of the report a general description of the Richmond Municipal Water District, with estimates of its probable future growth and water consumption, a discussion of the requirements of a modern water supply for a community of this character, and of the extent to which the water systems now in Richmond fulfill these requirements. Complete designs have been made of a distribution system to cover the urban portion of the district, and a careful study made of the parts of this complete design, which it is advisable to immediately install. This system has been designed to furnish an ample supply of fresh water at a pressure sufficient for adequate fire protection.

Three possible primary sources of supply have been carefully investigated, and general conclusions reached as follows:

1st. **Wells within the district.**—This supply has already been developed beyond its normal capacity so that both the quality and yield of water from the present wells in the district are deteriorating.

2nd. **Surface run-off within and immediately adjacent to the district**—This source of supply, composed chiefly of the watersheds of San Pablo and Wild Cat Creeks, is now controlled by the Peoples Water Company. The amount of water possible to obtain from this source is so limited in amount as to be insufficient for the ultimate demands. There appear to be serious questions regarding the legal feasibility of the project, especially concerning water-right ownerships and the possibility of the District being compelled to purchase the watersheds.

3rd. **Filtered water from the San Joaquin or Sacramento River.**—A supply of water can be readily obtained from this source, ample to meet all possible future demands and can by filtration be made of excellent quality. In this report it will be shown that from this source the Richmond Municipal Water District can obtain an ample supply of excellent water at adequate pressures, and that it can be distributed to consumers at rates much less than those now in force. The project can be made self-sustaining, so that the income from water sales will pay all operating costs and fixed charges, leaving the tax rates throughout the district unaffected.

At the close of this report are appendices describing the present or proposed water supplies of adjacent communities and discussing other technical subjects relating to the matters contained in the body of the report.

INITIATION AND PROGRESS OF THE WORK.

The Richmond Municipal Water District was organized under a legislative act of the State of California, approved May 1, 1911, and amended December 24, 1911. An election forming the district was held December 3, 1912. Shortly after this the Directors organized and on April 17, 1913, formally appointed Messrs. Haviland, Dozier & Tibbetts, Civil and Consulting Engineers of San Francisco, as Engineers for the District, with general instructions, as outlined above, to investigate the water situation. Since that time the engineering work has progressed steadily with a large field and office force.

Weekly meetings have been held with the Board of Directors, who have from time to time ordered detailed engineering reports on certain features of projects under consideration.

Formal reports have been submitted as follows:

No. 1—June 5, 1913—**"On Private Installation of Water Mains."**

No. 2—Oct. 2, 1913—**"Advance Statement on Filtered Water Supply from the Sacramento and San Joaquin Rivers."**

No. 3—Oct. 9, 1913—**"Advance Statement on Operating Costs for Filtered Water from the Sacramento River."**

Prior to the submission of these reports verbal reports had been rendered in some detail on the design of the distribution system, on the possible supply of water from wells, and on the San Pable Creek project of developing surface water by the construction of a large dam on lower San Pablo Creek.

The facts developed by reports Nos. 2 and 3 were deemed so favorable that instructions were given on October 9th to prepare a call for a bond election of $2,500,000.00 to bring filtered water from the Sacramento River to the Richmond Municipal Water District.

The present report, containing 400 pages of typewritten matter with 10 appendices on closely related subjects, 17 diagrams and 12 large maps and plates, is submitted so that all interested parties may know in full the facts relating to the Richmond Municipal Water District and the proposed source of supply and the proposed distribution system as recommended by the Board of Directors and its Engineers.

CHAPTER I
Description of District.

General Location and Area.

The Richmond Municipal Water District is in Contra Costa County, in the central westerly section of the State of California. It lies on the eastern shore of San Francisco Bay, immediately north of and adjoining the cities of Albany, Berkeley and Oakland. The center of the district is nearly opposite the Golden Gate, and about 12 miles in a direct line across the bay, northeasterly from San Francisco. It is bounded on the southwest by San Francisco Bay, on the northwest by San Pablo Bay, on the northeast by an irregular line approximating the eastern summit of the watershed of San Pablo Creek, and on the southeast chiefly by the Alameda-Contra Costa County line.

Included within the district is the entire city of Richmond, together with the remainder of the San Pablo Rancho outside of the municipal boundaries of Richmond, and all of the Sobrante Rancho, excepting the southeasterly portion thereof in the hills adjoining the Alameda-Contra Costa County line. It extends along the bay shore for a distance of about 18 miles from Pt. Pinole on the north to the Alameda-Contra Costa County line immediately south of Pt. Isabel on the south. It is approximately rectangular in shape, averaging about 6 miles in width in a north and south direction and 10 miles in length in an east and west direction. In the northeast part of the district are the greater part of the watersheds of Wild Cat and San Pablo Creeks, together with the gravel cones deposited by these creeks at the foot of the hills.

In the southwest part of the district, between the foot of the hills and the bay, is an extensive level plain upon which lies the City of Richmond and other towns to the south.

TOPOGRAPHY OF DISTRICT.

Classification of Land—Mountainous Areas.

The northeasterly portion of the district, comprising considerably over one-half of the total area, is formed by the mountainous watersheds of Wild Cat, San Pablo and Pinole Creeks, varying in height from 400 to 1,000 feet or more above sea level. In general, these hills are somewhat rounded, with moderate slopes partly covered with underbrush and scattering deciduous trees, and partly with grass, which affords good grazing land in the winter and spring. Except for a few rocky summits, there is a good covering of soil. Much of the western slopes has been subdivided and sold for residence purposes.

Adjoining San Francisco Bay in the westerly portion of the district is a detached group of hills called the "Potrero," about 5½ miles in length from Point San Pablo on the north to Point Potrero on the south, and about 1¼ miles in width. As much of this area is subdivided and must be served by a water distribution system a somewhat detailed description is justified.

Between Point San Pablo and Scofield Avenue at the Standard Oil Works the hill crest varies in a series of undulating knolls from 150

to 500 feet in elevation. The Scofield Avenue cut is about 50 feet in elevation at its summit. From Scofield Avenue, south to the Santa Fe tunnel site, is the lowest portion of the Potrero District, varying in elevation from 100 to 200 feet. Immediately to the south of the Santa Fe tunnel site, the summit rises to 370 feet; then drops to a pass of 180 feet elevation, then rises again to the point of a "Y" 320 feet high, from which radiate two ridges, one running southeasterly to Point Potrero and the other southwesterly to Point Richmond. The Point Potrero ridge rises to 340 feet then gradually descends to elevation 110 on the knoll near the point. The Point Richmond ridge varies from 200 feet on its higher summit to 100 feet in two low passes near its outer end. Most of the area south of the Santa Fe tunnel site is as yet unimproved grazing land, except on the northeast slope near the Santa Fe tunnel portal, where there are four closely built up residence blocks. Other tracts in this vicinity are being improved.

Formation of Hills.

The exposed cliffs, cuts, excavations, and the Santa Fe tunnel, show that the material underlying the earth mantle on the hills is a yellow metamorphic sandstone, soft and badly seamed, and at a greater depth a harder sandstone, mixed with occasional seams of basalt. The harder rock is extensively quarried by the San Francisco Quarries Co. near Point Castro, and the Healy Tibbitts Construction Company at Molate Point. It is used for concrete aggregate, road metal and rock fills.

Similar sandstone is found generally in the hills in the eastern part of the district, and in fact in all parts of the Coast Range of California. It is not usually permanently self-sustaining either in tunnels or in vertical cuts.

Marsh and Overflow Lands.

Within the confines of the district there are several thousand acres of marsh and swamp and overflow lands adjoining the Bays of San Francisco and San Pablo and mostly within the confines of the City of Richmond.

The marshy area covers a strip of land about ¼ to 1½ miles in width and 3 miles in length, containing about 2,000 acres. It is traversed by winding sloughs, and is so low that formerly at high tide the Potrero Hills formed an island. It was seriously proposed at one time to dredge a tidal canal completely through this marshy area, connecting San Pablo and San Francisco Bays, and isolating the Potrero. A large area near the center of the marsh has recently been filled in and reclaimed, and is used as railroad yards by the Santa Fe and as sites for several very important manufacturing plants. Additions have recently been made to the reclaimed areas to provide for further extensions of the Santa Fe railroad yards. These reclaimed areas connect the Potrero hills with the main developed portion of the city on the east of the marsh and divide the marshy area into two quite distinct portions. The northerly portion is the most extensive and is entirely undeveloped, being traversed by a network of sloughs and overgrown by rice grass, tules and other forms of aquatic vegetation. The southerly portion is higher and is traversed by one large winding slough ex-

tending inward from Ellis Landing, along the base of the Potrero hills. Private interests have straightened out a portion of this slough and dredged a channel into the marsh, using the excavated material for adjacent land reclamation. Along the southern edge of this section is the location of the proposed inner harbor developments, which will be constructed in the sheltered cove inside of Point Potrero, Brooks Island and Point Isabel. It occupies a particularly favorable position for ultimate development into a manufacturing and shipping and business district, because it will be immediately accessible to the inner harber, and is already surrounded on the landward side by developed city property, and by the yards and tracks of the Santa Fe Railroad. Its complete reclamation can be economically effected by filling it with material dredged from the inner harbor.

Level Area.

Including the swamp lands, the total area of land within the district below elevation 200, is about 25,000 acres, of which about 17,000 acres is comparatively level. Most of this is in a very gently sloping plain rising from the shore line at an elevation of 7 or 8 feet above mean low water, to the base of the hills at elevation 100 to 125 feet. Land above elevation 125 is usually on the hill slope, rising quite rapidly. The northern portion of this level area has been built up by gravel and sedimentary deposits from San Pablo and Wild Cat Creeks. Under normal conditions this is fed by underflow from these creeks so that until the last few years the water plane has been close to the surface of the ground. The level area contains most of the improved portions of the district, including the City of Richmond and practically all of the present population.

CLIMATOLOGY.

Temperature.

The climate of Richmond, in common with the balance of the San Francisco Bay region, is remarkable in many ways. Especially in the great uniformity of temperature. The mean annual temperature at San Francisco is about 55 degrees or practically the temperature of the Pacific Ocean at this latitude. The coldest month is January, with a mean temperature of 49 degrees. The warmest period of the year is the latter half of September and the first half of October, when the mean temperature is about 59 degrees. The highest temperature ever recorded is 101 degrees, and the lowest is 29 degrees. The small range in temperature is accounted for by the proximity of the Pacific Ocean and by the high summer fogs.

Rainfall.

The nearest station at which rainfall records are available is at the University of California at Berkeley, about 7 miles southeast of the center of the district. The annual rainfall as observed at Berkeley is plotted in the accompanying Diagram No. 10, page 198, and the table of monthly rainfalls is shown on page 194. This matter has been discussed in detail on pages 189 to 192 of Chapter VI of this report in estimating the probable runoff from surface watersheds. It will be seen that practically all of the rainfall occurs in the months of October to April, inclusive, and that by far the greatest portion falls dur-

ing the months of December, January and February. The summer months of June, July and August are practically rainless. During a period of 26 years, the average seasonal rainfall has been about 26.07 inches, with a minimum of 14.40 inches and a maximum of 46.00 inches. The average number of rainy days per year is 67, or less than 20 per cent of the total. Thunder-storms are practically unknown and a fall of snow is very rare and never remains for more than a few hours.

The long dry summer months increase the danger from fire, as frame buildings become unusually dry and the dead grass, covering the ground in unoccupied portions of the city, burns readily in the late summer and fall. As later discussed in detail, the uneven distribution of rainfall makes it necessary to provide large storage capacity as a part of any project depending upon the impoundment of surface waters as a primary source of supply.

Wind.

The only available wind records in this locality are those obtained from the government station on the Merchants Exchange Building at San Francisco. It is recognized that the interference of the mountain ranges around San Francisco Bay is so great that San Francisco records for wind travel indicate conditions in Richmond in only a very general way. From records covering a 3-year period from January 1, 1909, to December 31, 1911, summations were made of the total miles of wind travel past the San Francisco station at a velocity of 15 miles or more per hour, for each direction by 45 degree segments. The summation for miles of wind travel past the station from the different points of the compass is as follows:

North	N.E.	East	S.E.	South	S.W.	West	N.W.
0	1,865	0	1,709	4,502	25,637	31,969	1,594

These records have been platted on Diagram No. 1 so as to represent graphically a comparison of the wind travel in the different directions. On Diagram No. 2 have been platted the direction and velocity of all winds throughout the entire period that have a velocity of 30 miles or more per hour, as shown by the following tabulation:

Table No. 1—Wind Velocity and Direction.

Velocity (per hour))	Direction toward the	Number of Storms
40 or more miles	Northeast	4
35 to 40 miles	Northwest	1
35 to 40 miles	Northeast	4
35 to 40 miles	East	1
35 to 40 miles	Southwest	1
30 to 35 miles	North	5
30 to 35 miles	Northeast	32
30 to 35 miles	East	47
30 to 35 miles	South	1
30 to 35 miles	Southwest	3
30 to 35 miles	Northwest	4

IMPROVEMENTS IN DISTRICT.

Location of Urban Portion of District.

The urban portion of the district, including nearly all of the present population and principal improvements, covers about 7,000 acres, chiefly on the level plain between the shoreline and the hills, and on the eastern slopes of the Potrero Hills. This gives for the entire 7,000 acres an average population of less than 2½ per acre. This very low figure is the result of scattered improvements. There are scarcely any single blocks which are solidly built up, and in many blocks there are not more than one or two houses. The location of the improvements is indicated in a general way by the accompanying Plate 2 resulting from a survey made in July, 1913, during which a very rough classification was also attempted.

Location of Improvement Centers.

The topographical features of the City of Richmond have been previously outlined. The city is divided by a central marshy zone extending in a general north and south direction, into an eastern and western section.

During the past few years street improvements have been progressing at a rapid rate, and building has tended to concentrate along these improved streets in two sections, the older one at West Richmond and the newer one near the center of the plain at Sixth and Macdonald Avenues. Other portions of the community which are rapidly developing are San Pablo, Pullman, and Stege. The bulk of the population is still concentrated in the triangular area bounded by the Southern Pacific Railroad and by the main line and Oakland branch of the Santa Fe; and in a small area on the northeast slopes of the Potrero Hills near the Santa Fe tunnel.

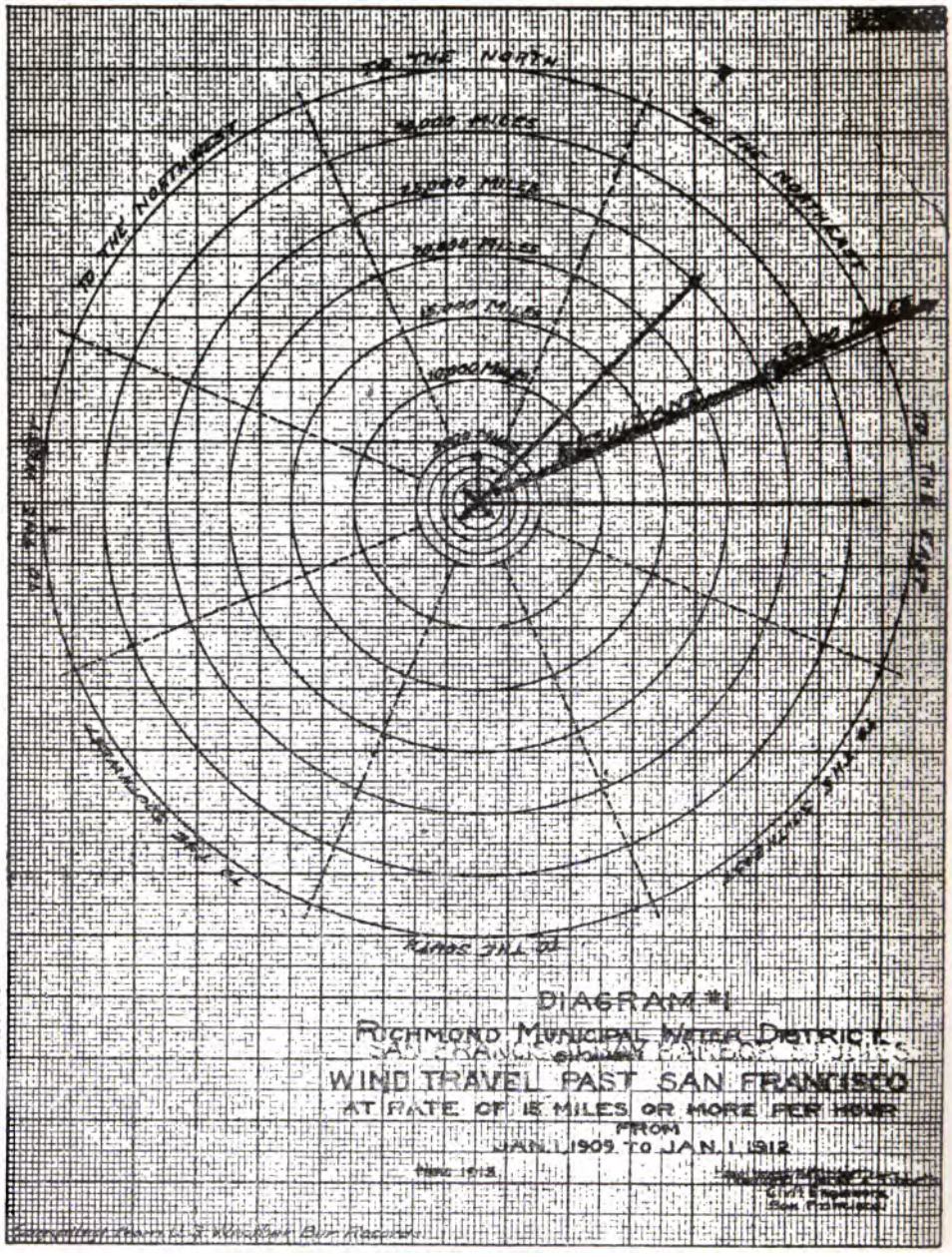
The Western Developed Section.

The western developed section is on the eastern slope of the Potrero Hills from Scofield Avenue south to the Santa Fe tunnel. Here is a well developed residence and business section, comprising the original town of Point Richmond, which was founded soon after the building of the Santa Fe Railroad, whose tidewater terminal is on the outer side of the Potrero Hills opposite. This improved portion is about 1¼ miles in length and covers the full width of the range of hills, extending southeasterly from the Standard Oil refineries to the Santa Fe Railroad tracks. Along the western edge of the Potrero District, lies the outer water front with a number of warehouses and manufacturing plants.

The area of the Potrero section over which streets have been laid out is about 340 acres, or about 17½ per cent of the total Potrero area of 1,960 acres.

The Eastern Developed Section.

The eastern, or newer section, has developed its business center along Macdonald Avenue, from Fourth to Seventeenth Streets, confined in an area two blocks wide with Macdonald Avenue in the center. There is a scattered residence section extending several miles north, north-



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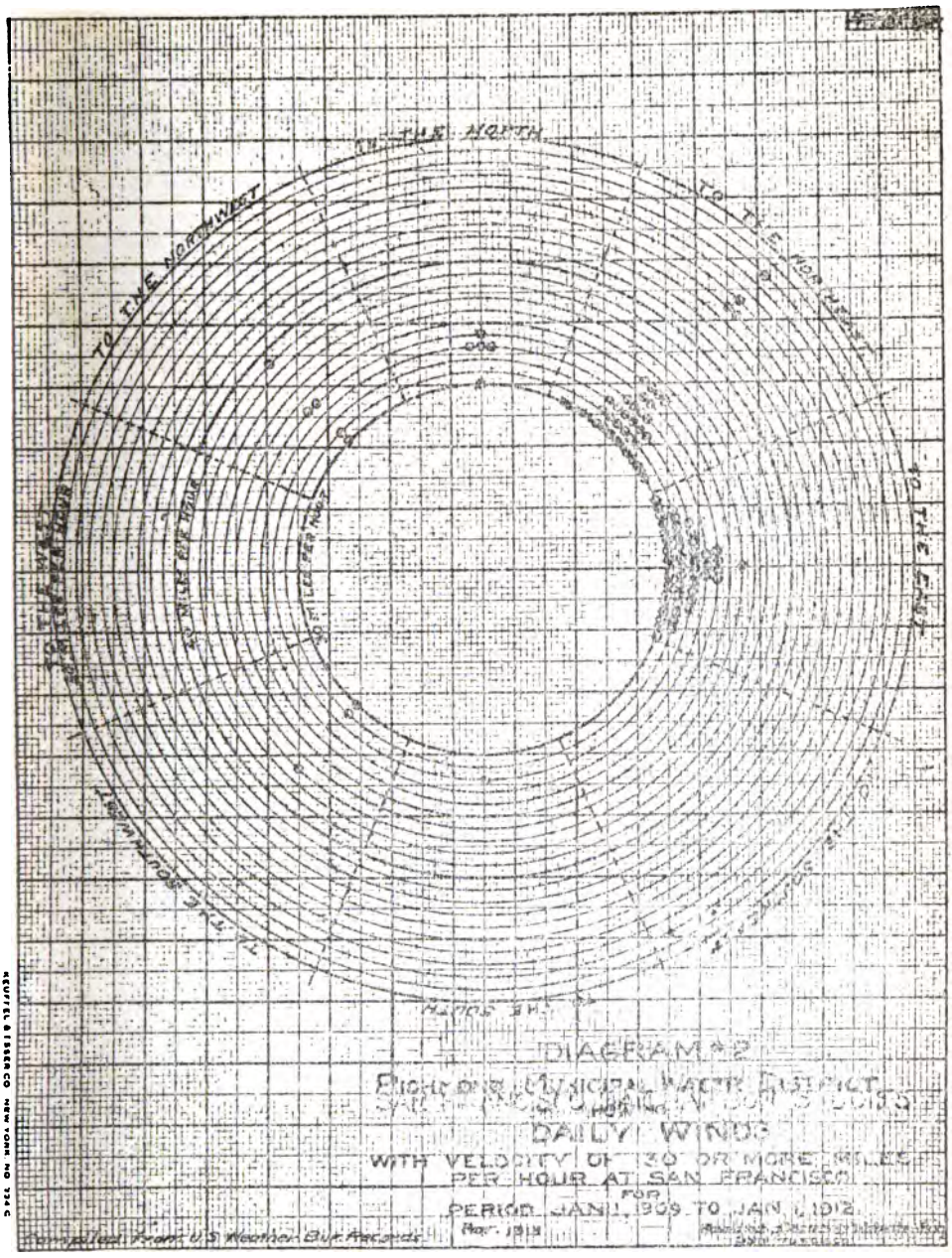

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east, south, east and southeast from this center. A number of factories have developed along the line of the Southern Pacific Railroad south of Macdonald Avenue.

The Southern Developed Section.

There is also a large area in the district and south of the Richmond City line which is being rapidly developed. This includes in part, some excellent and well improved residence sections, such as Richmond Annex, Richmond Junction Heights and Thousand Oaks.

Business Improvements.

At the present time the largest business blocks in the district are of brick construction and four stories in height. There are a few residences exceeding six rooms. In the West Richmond portion of the district the business development is fairly compact with brick and frame buildings closely adjoining each other.

Railroads.

The railroads in the City of Richmond form a letter "A" with its apex near the northern boundary of the city, where the Southern Pacific crosses the Santa Fe. From this point the Santa Fe extends in a general southwesterly direction through the north central factory portion of the city, the western factory portion adjacent to the Standard Oil Works and along the southeasterly edge of the developed section of West Richmond. It then passes through a tunnel under the Potrero Hills and in practically a straight line to the terminal wharves and ferry slips at Point Richmond, where the traffic is transferred on ferries to the City of San Francisco. About 1,500 feet south of Macdonald Avenue the Oakland branch of the Santa Fe extends in an east and west direction from a point near Point Richmond, crossing the Southern Pacific at about Twenty-third Street. The Southern Pacific extends from the apex of the letter "A" in a general southeasterly direction through the recently developed portion of the city, to Berkeley and Oakland. The Richmond Belt Line Railway begins at the apex of the letter "A," skirts the southern edge of the San Pablo marsh lands, runs around Point San Pablo, along the waterfront and southeasterly along the outer edge of the Potrero Hills to the California Wine Association wharf at Winehaven. A main traction line of the San Francisco, Oakland Terminal Railways extends along Macdonald Avenue from San Pablo Avenue near the eastern boundary line of the city, due east and west, through the center of the newer settled section to the Santa Fe Railroad, then turns and parallels the Santa Fe Railroad, finally crossing the same and extending into the older, or West Richmond District, through the Scofield Avenue cut to the San Pablo Quarries at Point Castro.

Principal Thoroughfares.

Macdonald Avenue, forming between the railroads the bar of the letter "A", is the principal street of the eastern section. Parallel to Macdonald Avenue, and nearly ¾ of a mile south, near the base of the letter "A", Cutting Boulevard extends across the town from the eastern boundary line near San Pablo Avenue due west to the center of the West Richmond section. This is a street 100 feet in width, afford-

ing the most direct line for traffic entering the City of Richmond from the foothill section, and from the cities of Berkeley and Oakland, to the south. Ashland Avenue has recently been paved paralleling the Santa Fe from Macdonald Avenue southwesterly to the West Richmond section, forming a broad boulevard directly connecting the centers of population of Richmond. Along the eastern base of the Potrero Hills, Standard Avenue and Richmond Avenue are the main thoroughfares leading northwesterly from the junction of Cutting Boulevard and Ashland Avenue and the Santa Fe Railroad. The traffic from the eastern section is taken by Ashland Avenue from Macdonald Avenue to this junction. The traffic from the southern section and the cities of Berkeley and Oakland is taken by way of the Cutting Boulevard, and the traffic from the West Richmond section is brought to the same point by way of Richmond Avenue and Standard Avenue, two blocks northwest. The principal recent developments of Richmond lie within the letter "A," between Cutting Boulevard and Ashland Avenue and its extension. The most available level area for further industrial development, particularly if the inner harbor project is carried through, will lie to the south of Cutting Boulevard and will use that street in reaching West Richmond. There will probably also be further developments along the outer side of the Potrero Hills in the territory served by the Belt Line Railroad.

ORIGIN OF RICHMOND.

The entire development of the City of Richmond has occurred since 1900. In 1899 the site of the present city was open grazing and farming land. In that year the Santa Fe Railroad began construction in this vicinity, selecting Richmond as a convenient deep-water terminal point on San Francisco Bay. In the year 1901 ferry traffic was first opened between San Francisco and Point Richmond, giving Richmond exceptional railroad facilities, as it was already located on the main line of the Southern Pacific, Ogden and Shasta routes. Since that time the growth of the city has progressed steadily and rapidly. The establishment of the Standard Oil refineries in 1902 furnished the second great stimulus to development.

In 1905 Richmond was incorporated as a city of the sixth class. On February 9, 1909, the new charter was ratified by the voters of the city, and on March 4, 1909, was approved by Act of the State Legislature giving Richmond a modern charter government, as a city of the fifth class.

Richmond owes its original foundation to the opportunity afforded for the construction of wharves and piers reaching out into deep water close to the natural shore line. The exceptional facilities for water and rail communication and the large area of level land, quickly brought to Richmond a large number of industrial concerns, so that the city has now a good claim to an important place in Central California as an industrial and manufacturing community. A conservative estimate in 1912 placed the total investment in 35 of the leading industries at over $25,000,000 and the monthly pay roll of these concerns at over $300,000. Among the large concerns worthy of mention are those in the following pages.

INDUSTRIES OF RICHMOND.

Standard Oil Works.

The Standard Oil refineries are the largest in this country west of New Jersey, and on account of their favorable location, and particularly because of their connection by pipe lines with the great oil fields of the upper San Joaquin Valley, should ultimately be the largest oil refineries in the world. The plant represents an investment, chiefly in permanent buildings, of over $15,000,000. It is soon to be enlarged by additional construction, which will increase its capacity 35 per cent. The plant is complete within itself, being fully equipped for the manufacture of boxes, cans and such other receptacles as may be required for the shipment of its products. The total holdings of the company in this locality aggregate 413.7 acres, most of which is at the narrowest point of the Potrero Hills, and not far from the geographical center of the city.

A substantial wooden pier 3,500 feet long extends to the pier head and ends in water 25 feet deep at low tide. This pier carries several pipe lines to the pierhead line, where large tank steamers are loaded with oil and other products of the works for shipment to important points on the Pacific Coast. There is a second pier 780 feet long on Point Orient for handling oil in the export trade. Besides the petroleum refining works, there is a secondary plant for the handling of whale oil and its products.

California Wine Association.

This industry was located here in 1906 and is now the central storage and shipping plant of the largest grape and wine-making company in California, receiving its products from its wineries in all the grape districts of the State. The main cellars, known as Winehaven, are on the outward or western slope of the Potrero Hills, toward the northern portion of the city. It includes a large number of substantial brick warehouses and other buildings devoted to wine-making and storage. These are contiguous to a pier and wharf reaching into deep water, from which shipments of California wine are made to all parts of the world. Twelve million gallons of wine pass in and out of Winehaven annually, and there is kept constantly in storage a year's supply of matured wines. Every kind of California wines and brandies are stored there. The holdings of the company aggregate 47 acres and represent an investment of about $3,000,000. This is now being increased by additional permanent investments, and is said to be the largest winery in the world.

Pullman Car Shops.

The Pullman car shops are one of the most recent, large industrial establishments to locate in this vicinity. They are located on a 20-acre tract in the newly annexed portion, immediately south of the main settled part of the city, and bordering the Southern Pacific's and Santa Fe's main lines. The company began building this plant in April, 1910, and have expended close to $2,000,000 in permanent improvements. It is the principal plant of the Pullman Company, west of the Mississippi, and is made up of large, modern, fireproof buildings, well equipped both for manufacturing and repair work.

Sante Fe Railroad.

The main transcontinental line of the Santa Fe Railroad was built to what has now become Point Richmond in the years 1899 to 1901. Ferry boats transfer passengers from Point Richmond to the Union Depot and Ferry Building at the foot of Market Street in San Francisco. Santa Fe cars are transferred on ferry boats and car floats at the foot of Channel Street, San Francisco. A large terminal freight yard is operated near the center of Richmond and is connected by a double track line, passing in a tunnel through the Potrero Hills to the piers and slips at Point Richmond, where there are public wharves as well as private wharves.

Near the center of the city are extensive car shops and repair plants, employing a large number of men. The holdings of the Santa Fe Railroad Company in Richmond aggregate 459.71 acres, 56.43 acres of which are non-operative property, 360.28 acres operative property and 43 acres right of way. The aggregate investment of the Santa Fe in Richmond is very large.

Local Railway Systems.

The Richmond Belt Line Railway has a wharf at Point San Pablo at the extreme northern end of the Richmond water front with a 30 foot low water depth, less than 200 feet from the natural shore line. This wharf is connected by rail around the northeasterly shore of the Potrero district, with the Santa Fe and Southern Pacific Railroads in the center of the manufacturing and business districts of Richmond. The Belt Line Railway is handling 1,400 freight cars monthly.

The San Francisco, Oakland Terminal Railways has a line connecting Richmond with Oakland, Berkeley and Albany by way of San Pablo Avenue, and entering Richmond near the Pullman car shops, and traversing the city along Macdonald Avenue. The headway between Oakland and Richmond is 10 minutes. This line extends through West Richmond and the Standard Oil refineries, to the San Francisco quarry plant on the westerly water front. A branch of the electric car line extends from the corner of Twenty-third and Macdonald Avenue to the town of San Pablo, north of Richmond. Another branch line extends along Ohio Street and crosses the city on Sixth Street to the north boundary line. Richmond is also connected with Oakland by a branch of the Santa Fe Railroad and by the main line of the Southern Pacific. Each of these railways run trains at short intervals through Richmond.

The Castro Point Railway and Terminal Company have been granted a franchise from Castro Point to the vicinity of Winehaven and will ultimately be connected with the Belt Line Railway.

The Southern Pacific fast suburban electric service connecting direct with the San Francisco ferry boats is now being extended into Richmond.

Los Angeles Pressed Brick Co.

The Los Angeles Pressed Brick Company has a large plant, manufacturing many sorts of pressed brick and tile. This company leases land along the southern part of the outer water front, between Point Richmond and Point Potrero. It has a small wharf, in shallow water,

from which shipments can be made to bay or river points. Most of the raw material used is mined from the adjacent hills.

Hercules Powder Co.

The Hercules Powder Company is at present a distinct corporation and its plant at Pinole has an assessed value of about $1,000,000. They employ about 400 men, with a monthly pay roll of $30,000.

Their situation regarding water is quite critical; another dry year might cause partial failure in their supply as their reservoirs are now the lowest they have ever been. They should welcome any change for relief from this danger.

Rock Quarries.

There are a number of quarry industries, located chiefly along the outer water front, which have an aggregate output of over 400,000 tons of rock per year. Among these concerns are the San Pablo Quarries Co., Healy-Tibbitts Co., John Nicholl Co., Hutchinson Co. Stege Crushed Rock Co., and the Continental Fireproof Co.

Other Industrial Concerns.

Among other more important manufacturing plants with land owned or leased in Richmond are the Berkeley Steel Co., California Cap Works, California Chair Co., Dupont Powder Co., Enterprise Lumber Co., Golden Gate Creamery, Jones-Slattery Planing Mill, Judson Powder Co., Metropolitan Match Co., Pacific Porcelain Ware Company, Pacific Sanitary Mfg. Co., which latter has just completed the construction of a large plant; Pioneer Electric Company, Richmond Brick Co., Richmond Furniture Company, Richmond Brewing & Malt Company, Richmond Pottery Company, Richmond Lumber Company, Richmond Dredging Company, Stauffer Chemical Works, Tilden & Eakle Lumber Company, Enterprise Foundry, Richmond Soda and Bottling Co., Richmond Chemical Co., Richmond Feed and Grain Co., Santa Fe Foundry Co., Stege Lumber and Hardware Co., Sterling Fixture Co., Union Tank Line Co., Water and Wind Power Co., Pacific Carbon Manfg. Co., Inner Harbor Lumber and Milling Co., Union Sulphur Phosphate Co., and Western Pipe and Steel Company, the latter being a very large concern.

Public Service Corporations.

The greater part of the district, as described in Chapters III and V, is furnished with its water supply by the Peoples Water Company, the same corporation serving the adjacent cities of Berkeley and Oakland. The local supply for Richmond is derived chiefly from artesian wells in the San Pablo district, a short distance north.

The Pacific Telephone and Telegraph Company furnishes Richmond direct communication with the other interbay cities. The Postal and Western Union Telegraph Companies, with the American District Messenger service, are also represented. Electricity for the city of Richmond for power and lighting purposes is distributed by the Western States Gas and Electric Company. This concern purchases its current from the Pacific Gas and Electric Company and supplies the city lighting service, as well as private consumers. The larger manufacturing concerns, such as the Standard Oil Company, Santa Fe and

Pullman Shops, purchase power direct from the Pacific Gas and Electric Company.

The Oakland Gas, Light and Heat Company has a high pressure gas main leading from Oakland into Richmond, from which gas is distributed for heating and lighting purposes.

Municipal Improvements.

The city has 40 miles of macadam and oiled macadam streets, 6 miles of asphalt pavement, and 43½ miles of sewers.

The parks of the district consist of Janice Park and East Shore Canyon Park within the city boundaries, and the Grand Canyon, Lafayette private parks without the city boundaries.

The Richmond School Department consists of 9 schools including one Union High School. There is also a Polytechnic Business College. A recent issue of $160,000 has been expended in building two new brick school buildings.

Real Estate Conditions.

The present valuations of property within the city are approximately as follows:

Outlying residence section, $15 to $25 per front foot; close in residence property, $40 to $60 per front foot; outlying business property, $40 to $160 per front foot; business property on principal street, $200 to $500 per front foot; factory site acreage, outlying and undeveloped, $1,500 to $2,000 per acre; factory site property, developed and close in, $2,000 to $5,000 per acre.

Insurance rates are as low as 60 cents per year on residence property on policies running 3 years and the average rate for business property might be conservatively placed at $2.00 on policies running one year.

Owing to its rapid growth Richmond is lacking in housing accommodations. There are a great number of small rooming houses, apartment houses, hotels and restaurants, but there is a constant demand for more.

Richmond's close proximity to the larger cities has heretofore caused a great deal of purchasing to be done in adjoining cities. However, with the continued growth of the city its stores are expanding and carrying additional stock, and the tendency is toward patronizing home industry.

Banking Conditions.

The banks of the City of Richmond are four in number: the Mechanics Bank, Bank of Richmond, First National Bank, Richmond Savings Bank. The growth of these banks can well be inferred from the fact that during the period from January 7, 1911, to January 14, 1912, the total deposits slightly more than doubled, and during the same period the total assets increased about 64 per cent. On November 1, 1913, the total deposits were $1,425,000 and the total assets $1,844,000.

Newspapers.

There are 5 newspapers in the City of Richmond, as follows: Two dailies, the Morning Independent and the Evening Record-Herald;

two weeklies, the Terminal and the Contra Costan, and one monthly, the Advance.

Miscellaneous Improvements.

The Richmond Industrial Commission and the Sequoia Commercial Club are two efficient and aggressive bodies of the city actively engaged in promoting its commercial growth.

Richmond has several theaters and a well equipped opera house, including two new brick theaters which have just been completed, with a seating capacity of 600 and 1,200 respectively.

Richmond has 16 modern office buildings and two similar buildings are now in the course of construction. A fine new 4-story and basement steel frame building for the Elks Hall Association is also near completion.

There are 15 churches in the City of Richmond.

In spite of the fact that Richmond is primarily an industrial community, the death rate of the city is only 5.3 per 1,000.

PROSPECTIVE COMMERCIAL GROWTH.

Harbor Project.

With a view toward profiting by the increasing commerce expected after the opening of the Panama Canal, Richmond has taken important steps toward the establishment of a large port, which can readily compete with the other large ports on the Pacific Coast. Comprehensive plans have been adopted for an ultimate development costing over $18,000,000, and giving sufficient room for approximately as much commerce as now handled at the city of San Francisco. Bonds have been voted to the extent of $1,170,000 for the construction of the first unit of this harbor project. This first construction will consist of wharves for the so called "Inner Harbor" extending well toward the center of the city and wharves at the outer harbor in deep water, access to which will be given by the construction of a large highway and tunnel through the Potrero Hills. It is expected that substantial aid will be received from the Federal government for this harbor work. The early completion of the first unit of the project should greatly accelerate the commercial and industrial development of the city.

Labor Conditions at Richmond.

The industrial growth of Richmond has been greatly facilitated by unbroken harmony between labor and employers. The Standard Oil Company, the largest employer in the city, has been noted throughout the country for the absence of serious strikes. Most of the industries located at Richmond have always paid satisfactory wages, and consequently have received the hearty co-operation of the working people and business men of the city.

Housing conditions are good, and although the number of available houses is smaller than could be desired, rents are reasonable and the working population have good opportunities to become independent, through investment in home sites at reasonable prices. An immense area of land has been subdivided for small home sites, close to the manufacturing centers. A vigorous campaign is kept up at all

times to induce immigration to the city. All of these things have given exceptional reliability and permanence to the industries of Richmond, which are favored by the promise of continued industrial peace.

Richmond, An Industrial City.

During recent years, the growth of Richmond has been on a sounder and more substantial basis than that of most California cities. In Chapter II and App. II is shown the past and present growth in population and valuation of the district, together with predictions for the future. These indicate, from a standard and conservative method of computation, a probable future population in 1920 of about 31,000 and in 1950 of about 115,000. The present population is about 15,600. Similar studies show that the present assessed valuation is about $19,400,000 and that this will probably increase in 1920 to about $35,000,000.

There are many reasons to believe that the future growth of the district, as thus indicated by theoretical considerations, will be greatly exceeded. Most of the large cities in this country owe their rapid rate of growth chiefly to the development of manufacturing industries. In California this line of development has been generally neglected. Richmond is one of the few cities which has been primarily developed as an industrial community. It has special advantages for such developments, among which are excellent railroad service, deep water, a large level area well adapted for manufacturing or terminal properties, proximity to a large city, which means a cheap and flexible labor market, and cheap fuel, which can be furnished by the pipe lines of the Standard Oil Company leading directly from the California oil fields. This is also a line of development which can profit most from the commercial stimulus following the completion of the Panama Canal, and of the 1915 World's Exposition at San Francisco. The promise of a large population for Richmond is also based upon the many advantages which it possesses in comparison with other cities contiguous to San Francisco. Already there have been sufficient industrial establishments to make it a place of particular importance among California cities. Because of its promise as a manufacturing center, it follows that the completion of the proposed harbor improvements and the securing of an abundant supply of pure, soft water, will be of more advantage to Richmond than similar works would be to any other of the bay cities. It should insure a growth both in population and in wealth far in excess of the normal and conservative estimates indicated by the theoretical studies of Chapter II.

CHAPTER II.

PRESENT AND FUTURE

Population and Water Consumption

A study of the present population, water consumption and valuation of the Richmond Municipal Water District, together with a forecast of the future for a period of years commensurate with the life of the proposed works is of fundamental importance.

Upon the present and future population depends the amount of water which will be used for domestic consumption, this factor furnishing a very good index of the total consumption. The total consumption of water is the most important factor affecting the design of the proposed water works. The quantity of water which the proposed works should be designed to furnish immediately must be predetermined, together with the quantity required at various times in the future.

From the nature of the case, estimates can only be approximate and must be based usually upon theoretical considerations founded on the most accurate data obtainable at the present time.

On the valuation in the district depends the advisable limit of its bonded indebtedness for any purpose, its possibility of supporting public improvements by taxation and the amount of property which should receive efficient fire protection. As this is of comparatively secondary importance, however, its detailed consideration is deferred to Appendix No. II.

PRESENT AND FUTURE POPULATION.

Past Growth of District.

Prior to 1900 the area now comprising the Richmond Water District contained but two small towns, San Pablo and Rust. The rest of the territory remained in its original condition of large ranches in the Wild Cat and San Pablo watersheds and smaller farms on the area between San Pablo and Rust. The population of the whole district in the year 1900 as nearly as can be ascertained was 1,805. The total population of the district on June 30, 1913, was estimated to be 15,585. (See Table No. 12.) The rapid growth of Richmond in the last 10 years has become common knowledge throughout the State of California. The present population of the City of Richmond alone is about 13,575. The population of the area in the water district outside of Richmond has increased at only a normal rate. At present the City of Richmond and the towns of Stege and San Pablo include 98 per cent of the total population of the district. Only about 300 reside in the rural sections comprising the school districts of Orinda Park, Mount Pleasant, Sheldon and Sobrante. The remainder, or 15,285, are in the urban communities of Richmond, Stege and San Pablo.

General Methods of Forecasting Population.

There are two general methods in use for forecasting population.

Method No. 1—By comparison with the rates of growth of similar cities of greater population, and,

Method No. 2—By a study of the past rates of growth of the city under consideration.

The conditions which affect a city's growth are so numerous and so intricate that it is impossible to predict the future with any degree of certainty, and inadvisable to attempt such predictions for more than 40 or 50 years in advance. Particularly under conditions in America, the growth of various cities at the same time, as well as the growth of any one city at different times, varies so widely that only very approximate estimates are possible.

The first method is usually employed in forecasting farthest into the future, although if applied to any large cities in America it will be found that their growth has been so recent and so rapid, that there are so few cities the growth of which it is possible to study for 40 or 50 years, that a good average cannot be obtained.

The second method of forecasting is usually employed for not over one or two decades in the future. This is because the rate of growth of any given city changes so much with its size and with local conditions that better results can be obtained for longer periods by observing the rates of growth of other cities similarly located and at the time they were of similar size.

FORECAST OF POPULATION BY METHOD No. 1—COMPARISON WITH OTHER CITIES.

Growth of American Cities.

Data has been compiled from the United States Census reports and is given in the following table No. 2 of the growth and population of the larger American cities from the year 1800 to the year 1910.

Table No. 2—Population of American Cities for Census Years.

Cities	1800	1810	1820	1830	1840	1850
Alameda	.....	.....	.....	.....	.....	.....
Baltimore	26,515	46,555	62,738	80,620	102,313	169,054
Boston	24,937	33,787	43,298	61,392	93,383	136,881
Brooklyn	2,378	4,402	7,175	12,406	36,233	96,838
Buffalo	.....	.....	2,095	8,668	18,213	42,261
Chicago	.....	.....	.....	.....	4,470	29,963
Cincinnati	.....	.....	9,642	24,831	46,338	115,436
Cleveland	.....	.....	.....	1,076	6,071	17,034
Detroit	.....	.....	1,422	2,222	9,102	21,019
Elizabeth	.....	2,977	3,515	3,455	4,184	5,583
Galveston	.....	.....	.....	.....	.....	4,177
Greater San Francisco	.....	.....	.....	.....	.....	34,870
Jersey City	.....	.....	.....	.....	3,072	6,856
Los Angeles	.....	.....	.....	.....	.....	1,610
Minneapolis	.....	.....	.....	.....	.....	.....
New York	60,515	98,373	123,706	202,589	312,710	515,547
Oakland	.....	.....	.....	.....	.....	.....
Oakland and vicinity, including Albany, Emeryville, Berkeley, and Piedmont	.....	.....	.....	.....	.....	.....
Paterson	.....	.....	.....	.....	7,596	11,334
Portland	.....	.....	.....	.....	.....	821
Pittsburg	.....	4,768	7,248	12,568	21,115	46,601
Sacramento	.....	.....	.....	.....	.....	6,820
San Francisco	.....	.....	.....	.....	.....	34,870
Seattle	.....	.....	.....	.....	.....	.....
St. Louis	.....	.....	.....	.....	16,469	77,860

Table No. 2 (Continued)—Population of American Cities for Census Years.

Cities	1860	1870	1880	1890	1900	1910
Alameda	460	1,557	5,708	11,165	16,464	23,383
Baltimore	212,418	267,354	332,313	434,439	508,957	558,485
Boston	177,840	250,526	362,839	448,477	560,892	670,585
Brooklyn	266,661	396,099	566,663	806,343	.....	.....
Buffalo	81,129	117,714	155,134	255,664	352,387	423,715
Chicago	109,260	298,977	503,185	1,099,850	1,698,575	2,185,283
Cincinnati	161,044	216,239	255,139	296,908	325,902	364,463
Cleveland	43,417	92,829	161,096	261,353	381,768	560,663
Detroit	45,619	79,577	116,342	205,876	285,704	465,766
Elizabeth	11,567	20,832	28,229	37,764	52,130	73,409
Galveston	7,307	13,816	22,248	29,084	37,789	36,981
Greater San Francisco	58,805	162,134	274,222	364,807	445,689	651,805
Jersey City	29,226	82,546	120,722	163,003	206,433	267,779
Los Angeles	4,385	5,728	11,183	50,395	102,479	319,198
Minneapolis	2,564	13,066	46,887	164,738	202,718	301,408
New York	813,669	942,292	1,206,299	1,515,301	3,437,202	4,766,883
Oakland	1,543	11,104	34,555	48,682	69,960	150,174
Oakland and vicinity	1,543	11,104	34,555	54,645	84,190	195,748
Paterson	19,586	33,579	51,031	78,347	105,170	125,600
Portland	2,874	8,293	17,577	46,385	90,426	207,214
Pittsburg	49,221	86,076	156,389	238,617	321,616	533,905
Sacramento	13,785	16,283	21,420	26,386	29,282	44,696
San Francisco	56,802	149,473	233,959	298,997	342,782	416,912
Seattle	.....	1,107	3,533	42,837	80,671	237,194
St. Louis	160,773	310,864	350,518	451,770	575,238	687,029

From Table No. 2 has been constructed Diagrams Nos. 3 and 4 showing graphically the growth in population of the larger cities of the country from the years 1800 to 1910. The curves representing the several cities stand apart from each other, and show the comparative size of each of the cities at each decade. The slope of the curves also shows the relative rates of growth.

Method of Obtaining Weighted Means of Future Growth.

An attempt has been made to obtain a more probable mean or normal growth than by merely taking the average of the rates of growth of all the cities plotted. Some members of the group of cities will resemble the one under consideration more than others, so that if more weight is attached to those with the greatest resemblance, a more probable mean rate of growth will be obtained. The first step in this method is to choose a number of cities similar to the one under investigation. A table is next made showing the principal factors which influence the rate of growth of cities. Some of these factors have a greater influence upon the rate of the city's growth than others. The relative importance attached to each of the various factors is shown by the percentage values assigned. These are arbitrary and a matter of individual opinion, but any reasonable variation will leave the final results substantially the same.

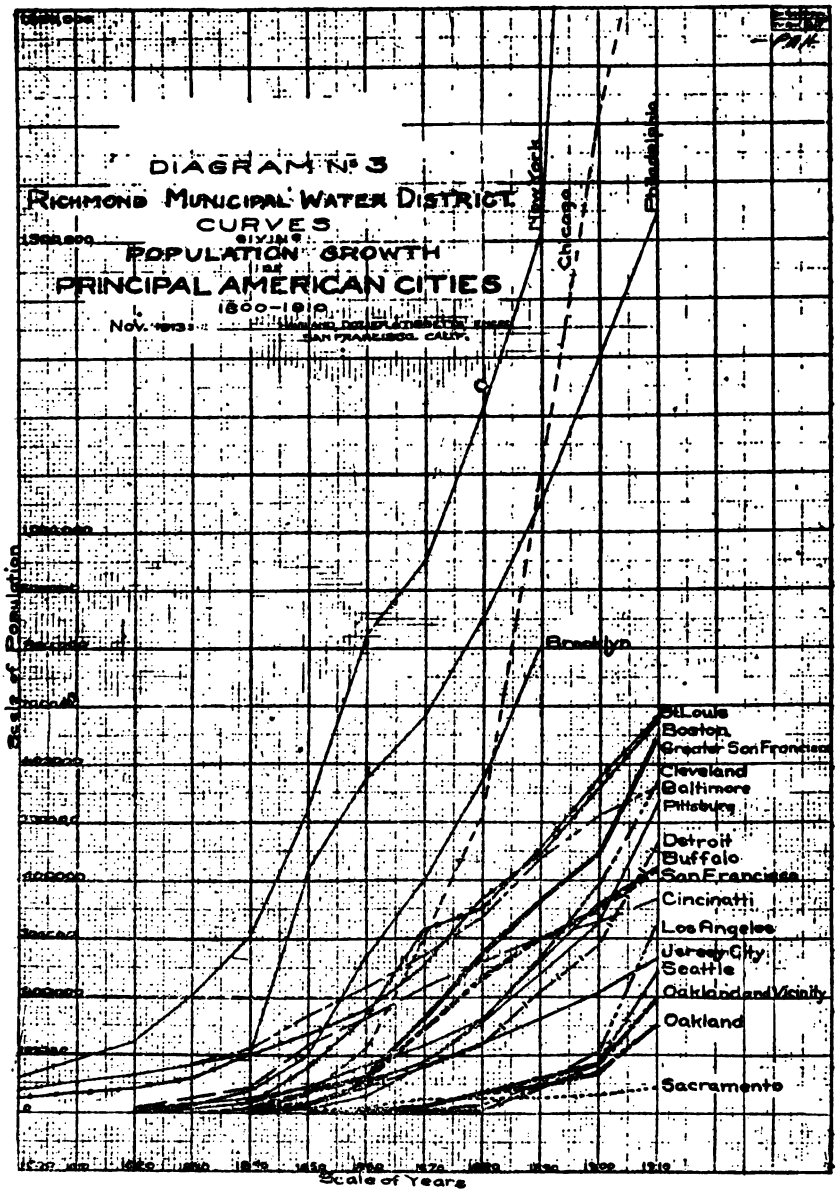


DIAGRAM N° 3
RICHMOND MUNICIPAL WATER DISTRICT
CURVES
GIVING
POPULATION GROWTH
OF
PRINCIPAL AMERICAN CITIES
1800–1910
Nov. 1913
SAN FRANCISCO, CALIF.
New York
Chicago
Philadelphia
Brooklyn
St. Louis
Boston
Greater San Francisco
Cleveland
Baltimore
Pittsburg
Detroit
Buffalo
San Francisco
Cincinatti
Los Angeles
Jersey City
Seattle
Oakland and Vicinity
Oakland
Sacramento
Scale of Population
Scale of Years

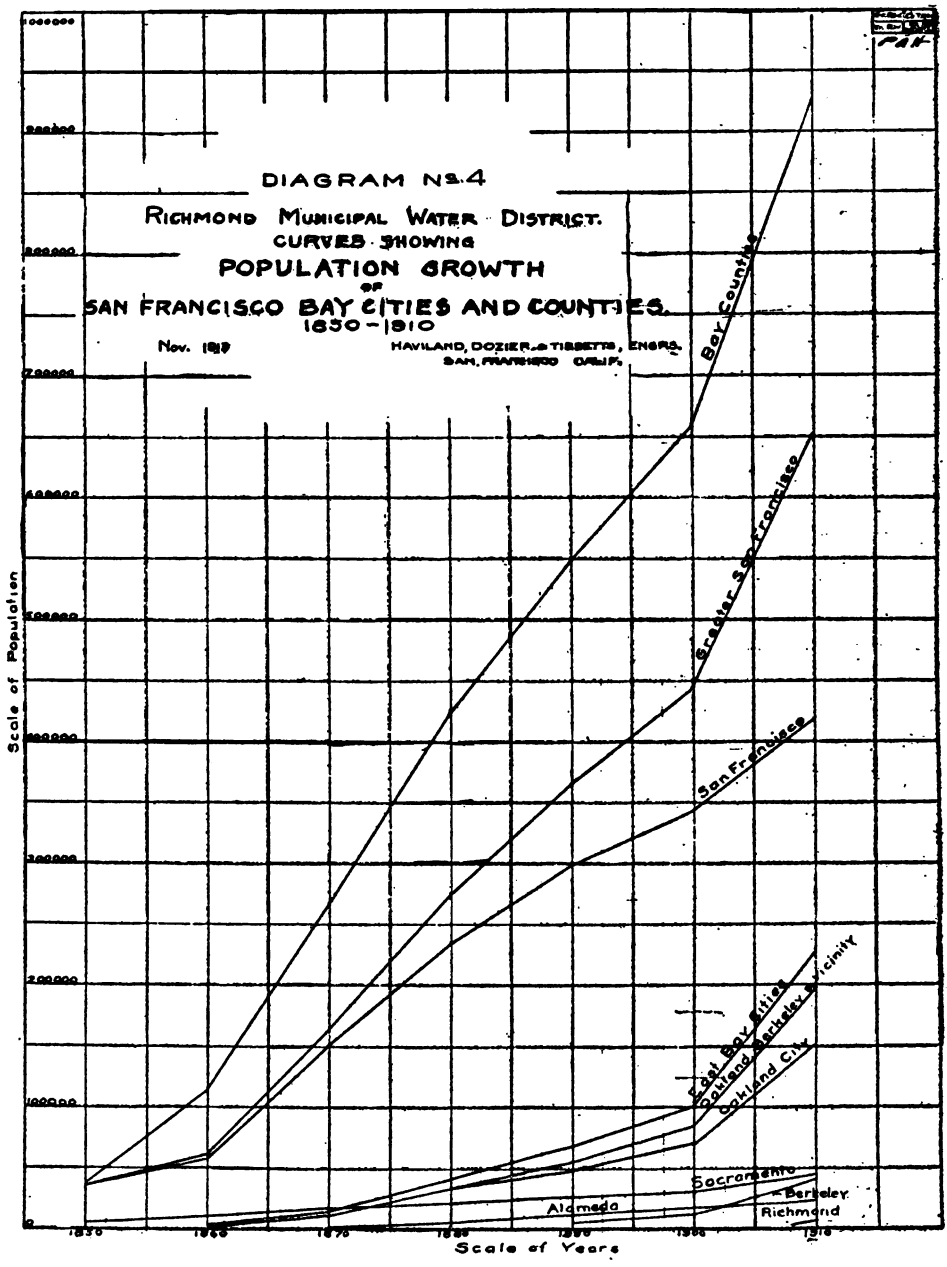


DIAGRAM No. 4
RICHMOND MUNICIPAL WATER DISTRICT.
CURVES SHOWING
POPULATION GROWTH
OF
SAN FRANCISCO BAY CITIES AND COUNTIES.
1850 - 1910
Nov. 1912
HAVILAND, DOZIER & TIBBETTS, ENGRS.
SAN. FRANCISCO CALIF.
Bay Counties
Greater San Francisco
San Francisco
East Bay Cities
Oakland Berkeley & vicinity
Oakland City
Sacramento
Berkeley
Alameda
Richmond
Scale of Population
Scale of Years
1850
1860
1870
1880
1890
1900
1910

Table No. 3—Factors Controlling the Rate of Growth of American Cities.

No.	Factor	Relative Weight Percentage
1	Commercial resources of tributary territory	20
2	Water transportation	15
3	Railroad communication	15
4	Topography and area	10
5	Geographical location	10
6	Climatic conditions	10
7	Location relative to other centers of population	5
8	Character of residents and civic spirit	5
9	Age of city and surrounding country	5
10	Previous rate of growth	5

For the city whose future is to be forecasted, there is next prepared a table describing in detail the local situation in regard to each of the factors controlling the growth of cities as shown in table 3. A table of this sort has been prepared for Richmond as follows:

Table No. 4—Characteristics of the City of Richmond Corresponding to the Factors of Table No. 3.

1. Large rapidly developing territory, rich in natural resources and tributary to San Francisco Bay.
2. A seaport on one of the finest harbors in the world, where commercial growth will be accelerated by the early completion of the Panama Canal.
3. The terminal of one transcontinental railroad system and traversed by one other transcontinental railroad system. Electric railroad and ferry connections with two large cities.
4. Situated upon a coastal plain with sufficient area for industrial development. A deep water frontage at the base of a low range of hills and a shallow water frontage on two sides. Ample area in immediate rear adapted to residential expansion.
5. A western American city (a rapidly developing section).
6. A mild and equable climate, which renders it possible to keep all lines of communication open throughout the entire year.
7. Contiguous to several other large cities, including San Francisco, Berkeley and Oakland.
8. A cosmopolitan population, composed chiefly of industrial and business people. A business community actuated by exceptional energy, optimism and unity of purpose.
9. City incorporated in 1905 in the vicinity of a large city founded in 1850.
10. Exceptionally rapid growth from a population of nothing in 1900 to a population of about 13,515 in 1913. Rapidly developing environs.

A list of cities is now chosen to compare with the one under investigation. Each of the cities in this list is carefully considered with reference to each of the factors controlling the growth of cities as shown in Table No. 3, and comparison made with the city under consideration. If the situation with respect to each of these factors closely resembles the city whose future is being investigated, then the factor is assigned the same percentage weight, otherwise it is assigned a smaller percentage as the conditions justify. The sum of the weights assigned to all factors for each city will finally give, as a percentage, the relative similarity of each of the cities listed with respect to the one under consideration. This total of the weights for all of the characteristics named is equal to 100 per cent if the city under consideration exactly resembles in all respects the one under investigation, and the nearer each of the cities resembles it, the higher is

their percentage weight, always being less than 100. The weighted mean population of the city considered for any decade is then obtained by using the total weights as multiplying factors; multiplying the population of each city by such factor and dividing the sum of the products by the sum of the factors. The weighted mean curve is then plotted from the population computed as above at each decade. (See Diagram No. 5.)

The following table gives the numerical results obtained as above described by comparing Richmond with other somewhat similar cities in the United States.

Table No. 5—Population Forecast, Weighted Mean—Richmond.

Cities Compared.	Weight of Factor.										Degree of Similarity.
Factor of Table No. 3.....	1	2	3	4	5	6	7	8	9	10	
Oakland	20	15	12	8	10	10	5	3	3	5	91%
Seattle	15	12	10	10	10	7	2	5	3	5	79%
Portland	15	10	7	7	7	7	7	3	3	3	69%
Galveston	15	12	5	3	8	8	0	4	3	2	60%
Detroit	10	5	6	6	6	3	0	4	3	3	46%
Cleveland	7	6	7	6	4	6	0	4	2	4	46%
Paterson	10	0	8	5	0	5	5	4	0	5	42%
Elizabeth	8	0	8	5	0	5	5	4	0	1	36%
Pittsburg	10	5	7	4	0	3	0	4	0	2	35%
Minneapolis	10	0	5	4	4	3	2	2	1	2	33%

The final results obtained by this method of forecasting the future population is shown in the last column in Table No. 12, the figures tabulated being read directly from Diagram No. 5.

The general subject of forecasting the population of the San Francisco Bay region is very fully discussed in Appendix No. 2 of the "Report on the Richmond Harbor Project," with supplementary report on "The Tunnel and Roadway" submitted to the Council of the City of Richmond by Haviland and Tibbetts, Civil Engineers, in September, 1912.

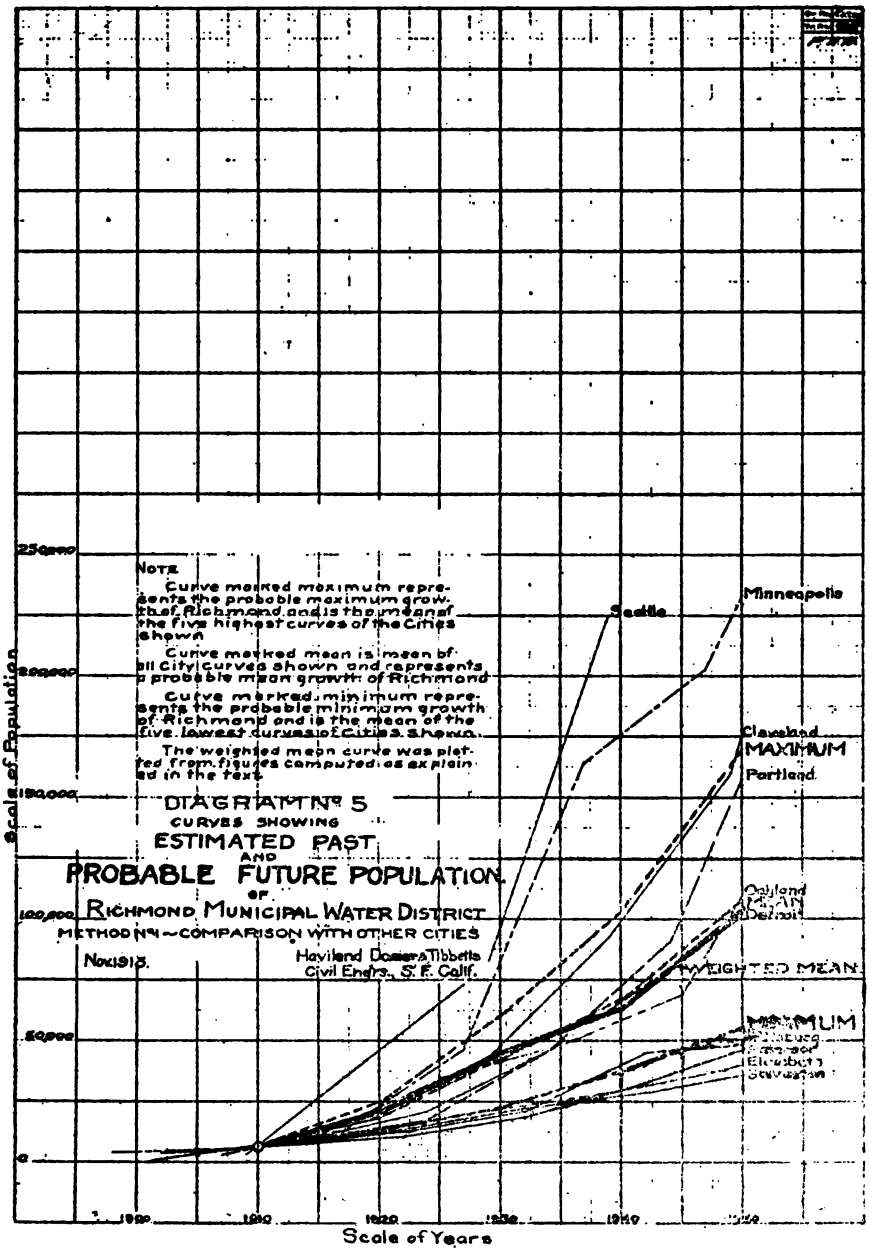
It has been assumed that the future population of the City of Richmond will so nearly include all the population of the Richmond Municipal Water District that they may be taken as one and the same. This is reasonable because the natural extension by annexation to the City of Richmond will in the very near future include all of the area from the Alameda County line on the south to the north boundary line of the Water District, and from the crest of the western boundary of the Wild Cat watershed on the east to the bay on the west. The rural population in the Wild Cat and San Pablo watersheds will remain practically negligible as it is at present.

FORECAST OF POPULATION BY METHOD No. 2—COMPARISON WITH PAST RATES OF GROWTH.

The estimate of the growth of population by Method No. 2 depends upon a careful analysis of the rate of growth of the Richmond District as far back as reliable data is obtainable.

Census Records.

The starting point of such a study is the population for the district as given by the United States Census Bureau reports in the years


NOTE
Curve marked maximum represents the probable maximum growth of Richmond and is the mean of the five highest curves of the Cities shown
Curve marked mean is mean of all City curves shown and represents a probable mean growth of Richmond
Curve marked minimum represents the probable minimum growth of Richmond and is the mean of the five lowest curves of Cities shown.
The weighted mean curve was plotted from figures computed as explained in the text
DIAGRAM No 5
CURVES SHOWING
ESTIMATED PAST AND PROBABLE FUTURE POPULATION OF RICHMOND MUNICIPAL WATER DISTRICT
METHOD No 1 ~ COMPARISON WITH OTHER CITIES
Nov. 1913.
Haviland Dosser & Tibbetts Civil Engrs., S. F. Calif.
Scale of Population
Scale of Years
Seattle
Minneapolis
Cleveland
MAXIMUM
Portland
Oakland
MEAN
Detroit
WEIGHTED MEAN
MINIMUM

1900-1910. The boundary lines of the Richmond Municipal Water District do not correspond exactly to any group of political subdivisions for which the population is enumerated in the census reports. The census for 1900 gave the population of supervisorial districts and incorporated towns, as the smallest political subdivisions. The Richmond Municipal Water District is a part of Supervisorial District No. 1 of Contra Costa County as it existed in the year 1900. Supervisorial District No. 1 included also the town of Martinez and the whole northwest rim of Contra Costa County, so that an exact determination of the population of the Richmond Municipal Water District in 1900 is impossible. An approximation has been reached by taking the ratio of the population to the registered voters in the whole supervisorial district and applying this as a multiplying factor to the number of registered voters in the year 1900 in the precincts of Giant, and San Pablo Nos. 1 and 2, which included all of the present Richmond Municipal Water District. A similar estimate was made by using the school enrollment. The average population estimated by these two methods was 1,805. The population of the district in the year 1910 is given in the census reports for judicial townships. Judicial townships Nos. 7, 10 and 15 cover practically the same area comprised in the Richmond Municipal Water District. The combined population given for these three townships in 1910 was 9,613.

The estimate of the population of the district between the years 1900 and 1910 and following 1910 is based upon the registered voters and the school enrollment.

Registered Voters.

Table No. 6, gives the registered voters in the election precincts of Richmond, Stege, Giant and San Pablo for the years of 1898 to 1912 inclusive, as shown in the great register of Contra Costa County. The number of voters in Richmond in May, 1913, is taken from the register for the last municipal election. For other precincts it is assumed the same as in 1912.

Table No. 6—Registered Voters 1898-1913.

	Precincts				
Year	Richmond	Stege	Giant	San Pablo	Total
1898	*....	*..	48	303	351
1900	*....	*..	50	303	353
1902	628	104	51	176	959
1904	570	104	55	187	916
1906	1,538	143	53	216	1,950
1908	1,811	275	51	222	2,359
1910	1,656	286	48	234	2,224
1912	2,952	286	44	239	3,521
1913	3,130	286	48	240	3,704

*Registered in other districts. (Compiled from Great Register in office of County Clerk of Contra Costa County. Registered voters include males only.)

(For the year 1900 the number of voters was taken as the mean of 1898 and 1902.)

Estimate of Population Based on Registered Voters.

This estimate is shown in Table No. 7 as given below.

The method of computation is self-evident. It appears that the number of voters in proportion to the population was greater before the periods of growth in Richmond. This is reasonable because of the fact that large numbers of single men came to Richmond as employees of the various industrial establishments there, thereby raising the proportionate number of voters. Similar factors computed for the cities of Sacramento, San Francisco, Oakland, Berkeley, Alameda and Piedmont, in the year 1910 range from 4.5 to 6.02 and average 5.15.

Table No. 7—Estimate of Population Based on Registered Voters.

Year	Actual Population	Registered Voters	Ratio Population to Voters	Estimated Population	Annual Per Ct. Increase
1900	1,805	353	5.1	....	.....
1901	....	...	...	....	165.5
1902	....	959	5.0	4,795	.....
1903	....	...	...	....	6.5
1904	....	916	4.9	4,485	.....
1905	....	...	...	....	104.1
1906	....	1,950	4.7	9,165	.....
1907	....	...	...	....	15.7
1908	....	2,359	4.5	10,600	.....
1909	....	...	...	....	—10.3
1910	9,613	2,224	4.3	....	.....
1911	....	...	...	....	57.3
1912	....	3,521	4.3	15,120	5.2
1913	....	3,704	4.3	15,920	.....

School Enrollment.

Enrollment in the grammar school districts of Richmond, Stege, San Pablo, Orinda Park, Mt. Pleasant, Sheldon and Sobrante, is given in the following table No. 8, comprising practically the same area as the Richmond Municipal Water District. A deduction was made for a portion of Sobrante School District which is not within the water district, and for Orinda Park District, only a small portion of which is within the water district. The enrollment is given for the school year ending in June of each year from 1900 to 1913, as shown on the official records of the County Superintendent of Schools.

Table No. 8—Enrollment in Grammar School Districts Comprising Richmond Municipal Water District.

Year	Richmond	Stege	San Pablo	Orinda Park	Mount Pleasant	Sheldon	Sobrante	Total
1900	*...	*..	199	16	13	25	23	276
1901	*...	*..	271	17	18	28	24	358
1902	*...	*..	364	17	16	11	27	435
1903	277	85	140	14	16	13	28	573
1904	425	90	135	16	17	12	26	721
1905	575	82	139	18	16	11	23	864
1906	605	88	153	19	19	6	21	911
1907	775	124	152	20	26	**	19	1,116
1908	916	136	152	14	26	**	15	1,259
1909	963	177	134	9	26	**	18	1,327
1910	910	186	143	23	21	**	22	1,305
1911	1,030	233	132	15	12	6	24	1,452
1912	1,230	281	140	18	12	18	16	1,715
1913	1,850	inc. Stege	151	19	8	15	20	2,063

*Not in existence. **Lapsed.

Estimate of Population Based on School Enrollment.

This estimate is tabulated in Table No. 9. The method of computation is similar to Table No. 7. The ratio of population to enrollment increases from 6.5 in 1900 to 7.4 in 1910, showing that the proportion of children to the population was greater in the year 1900 than in 1910. Similar ratios computed for other bay cities show a range in 1910 from 6.78 to 10.26 with an average of 8.2.

Table No. 9—Estimate of Population Based on School Enrollment.

Year	Actual Population	School Enrollment	Ratio Population to Enrollment	Estimated Population	Annual Per Ct. Increase
1900	1,805	276	6.5	....	....
1901	....	358	6.6	2,360	30.7
1902	....	435	6.7	2,915	23.5
1903	....	573	6.8	3,900	33.7
1904	....	721	6.9	4,980	27.6
1905	....	864	7.0	6,048	21.4
1906	....	911	7.1	6,470	6.9
1907	....	1,116	7.2	8,040	24.2
1908	....	1,259	7.3	9,200	14.3
1909	....	1,327	7.4	9,820	6.7
1910	9,613	1,305	7.4	....	—2.1
1911	....	1,452	7.4	10,750	11.9
1912	....	1,715	7.4	12,680	17.9
1913	....	2,063	7.4	15,250	20.2

Directory Names.

The number of names in the directory for the Richmond District indicates in a general way the growth of population there, but does not seem to be reliable because the application of the usual multiplying factor to the figures results in a population much larger than the figures obtained from the school enrollment and the registered voters. It has not been used as a basis for the estimation of population in this report. However, the figures for the directory are given as a matter of interest in Table No. 10.

Table No. 10—Number of Names in Richmond Directory.

Year	Names in Directory	Factor	Estimated Population
1909	3,422	....	9,150
1910	3,593	2.68	9,613
1911	5,452	....	14,570
1912	5,942	....	15,900
1913	7,282	....	19,500

Average Estimated Population.

Table No. 11 is a combination of Tables Nos. 7 and 9. The most probable population for the Richmond District between 1900 and 1913 is taken as the average of the two sets of figures obtained by the two methods in Tables Nos. 7 and 9. The average increase in population for the past 12 years appears to be about 16 per cent per year.

This is the most probable figure to be used for forecasting, because the first year's increase in population, representing the beginning of growth of a city, is obviously abnormal.

Table No. 11—Average Estimated Population.

Year	Population Based on School Enrollment	Population Based on Voters	Average Population	Annual Per Ct. Increase
1900	....	....	1,805	....
1901	2,360	....	2,830	56.7
1902	2,915	4,795	3,855	36.3
1903	3,900	....	4,294	11.3
1904	4,980	4,485	4,732	10.1
1905	6,048	....	6,275	32.6
1906	6,470	9,165	7,818	24.5
1907	8,040	....	8,859	13.3
1908	9,200	10,600	9,900	11.7
1909	9,820	....	9,756	—1.4
1910	....	....	9,613	—1.4
1911	10,750	....	11,756	22.3
1912	12,680	15,120	13,900	18.2
1913	15,250	15,920	15,585	12.1
Total				+251.9
				—2.8
				13/249.1

Average for past 12 years = 16%. Average for 13 years = 19.1%.

Forecast of Probable Future Population.

In Table No. 12 are given 3 columns of figures, headed "Maximum Population," "Mean Population" and "Minimum Population" for the years 1913 to 1925 inclusive, and every 5 years thereafter. The maximum probable future population is computed upon a decreasing compounded percentage, between the years tabulated, beginning with 16 per year to 1925. Thenceforward the percentage increase per decade decreases to 20 per cent for the half decade from 1950 to 1955. The minimum probable future population begins with an increase of 8 per cent decreasing to 5 per cent, compounded yearly to the year 1925, thenceforward on a decreasing rate to 10 per cent for the half decade 1950 to 1955. The **mean** probable future population is the average of the maximum and minimum. In a parallel column is tabulated figures read from Diagram No. 4, forecasting under Method No. 1 for forecasting population as previously discussed. The resulting figures for the year 1955 as obtained by Methods Nos. 1 and 2 are 123,250 and 134,000 respectively.

The close concurrence of the above results is a satisfactory indication of the probable accuracy of the forecast. The fact that the forecasted population of Richmond by comparing it with its own past rate of growth gives larger results than by comparing it with the other large cities, merely indicates the strategic excellence of Richmond's position as a potentially great industrial city.

Table No. 12—Forecast of Probable Future Population. Annual Rates and Resulting Populations.

Year	Pct.	Max. Pop.	Mean Pop.	Pct.	Min. Pop.	Pop. from Dia. No. 5
1913	....	15,585	15,585	...	15,585	10,760
1914	16.0	18,100	17,470	8.0	16,840	12,080
1915	15.0	20,800	19,470	7.7	18,140	13,400
1916	14.0	23,700	21,600	7.4	19,500	14,720
1917	13.0	26,800	23,850	7.1	20,900	16,040
1918	12.0	30,000	26,160	6.8	22,320	17,360
1919	11.0	33,300	28,600	6.5	23,900	18,680
1920	10.0	36,630	31,015	6.2	25,400	20,000
1921	9.0	39,600	33,250	5.9	26,900	22,500
1922	8.0	42,800	35,600	5.6	28,400	25,000
1923	7.0	45,800	37,875	5.3	29,950	27,500
1924	6.0	48,600	40,050	5.0	31,500	30,000
1925	5.0	51,100	42,100	5.0	33,100	32,500
1930	30.0	66,500	53,950	25.0	41,400	45,000
1935	25.0	83,200	66,450	20.0	49,700	53,750
1940	23.0	102,300	81,000	20.0	59,700	62,500
1945	22.0	124,800	96,750	15.0	68,700	82,750
1950	21.0	151,000	115,050	15.0	79,100	103,000
1955	20.0	181,000	134,000	10.0	87,000	123,250

The results tabulated in Tables Nos. 11 and 12 are shown graphically in Diagram No. 6.

The maximum, mean and minimum curves represent corresponding figures in Table No. 12. The estimated population given for the year 1913 is taken from Table No. 11 and plotted in the lower left-hand corner of the Diagram.

Summary of Probable Future Population and its Relation to Water Consumption.

It is thought wise to use as a basis for the prediction of future water consumption the figures obtained by method No. 2 for the mean probable future population as shown graphically in Diagram No. 6 and tabulated in Table No. 12. In the following discussion this mean probable future population is tabulated in conjunction with the predictions for future water consumption in Tables Nos. 16 and 17.

PRESENT AND PROBABLE FUTURE WATER CONSUMPTION OF THE DISTRICT—QUANTITY NOW IN USE.

Sources of Information.

Much time was spent in collecting all available data and measurments of water supplied within the district. General managers, and superintendents of industrial establishments were consulted by letter and personal interview for information concerning the production and consumption of water at their works. Figures were compiled in the offices of the water companies directly from their records and from personal interviews with their Chief Engineers. The Peoples Water Company in particular furnished quite complete data on the production and consumption of water, not only from their own sources, but from private supplies as well. They also furnished estimates of the water pumped out of the District from the San Pablo Wells to Berkeley from the records of the Rose Street pump in Berkeley, where

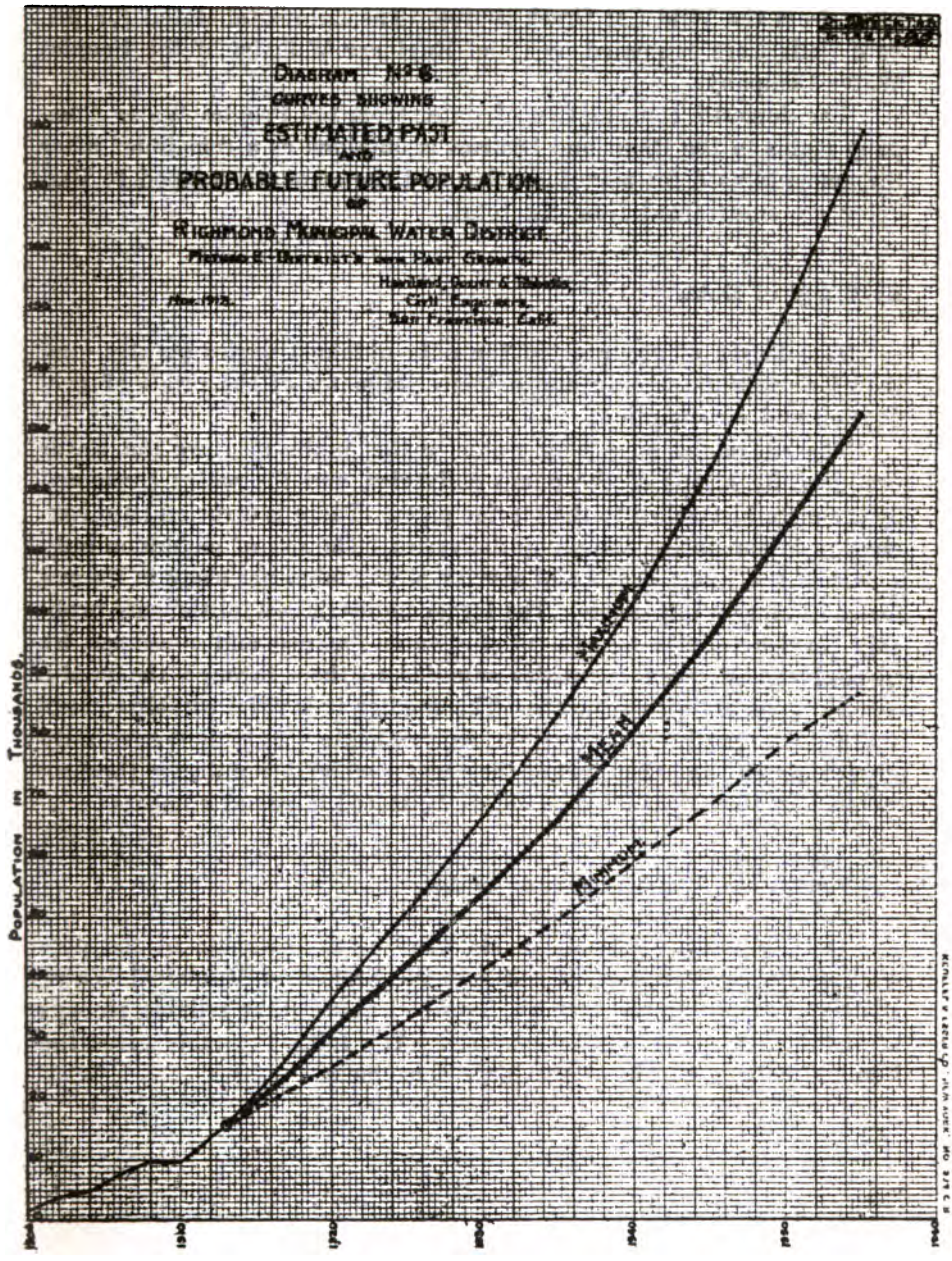


DIAGRAM No 6.
CURVES SHOWING
ESTIMATED PAST
AND
PROBABLE FUTURE POPULATION
OF
RICHMOND MUNICIPAL WATER DISTRICT
Hazen
Merrill
Ripley
POPULATION IN THOUSANDS.

the water is repumped. Also estimates of the quantities pumped by the Hercules Water Company, to Pinole and by the Peoples Water Company from the Wild Cat Creek source. The figures tabulated for private wells were estimated by Chief Engineer Wilhelm of the Peoples Water Company.

The domestic consumption of water from the Peoples Water Company mains in the Richmond District is obtained as a remainder after the amounts used for manufacturing and the amounts pumped to Berkeley are substracted from the total.

Accuracy of Data.

The degree of accuracy of the data obtained varies greatly, and therefore permits of only approximate estimates of the totals of production and consumption.

The companies supplying water to the public measure the water produced by means of the pump deliveries, and the water consumed by the meters attached to the service pipes. There is error and approximation in computing the pump deliveries. The use of meters on only a part of the whole number of service pipes makes accuracy in figures for consumption impossible. The larger industrial establishments probably furnish reliable figures for the water pumped and consumed by themselves. Metered quantities supplied to them through the public service pipes are also accurate. The smaller industrial establishments and private parties having wells can estimate pump deliveries only approximately, and that part of their water which is not drawn through metered service pipes must therefore be stated in round numbers.

Production and Consumption of Water.

It is extremely difficult to make an actual estimate of the production and consumption of water in the Richmond Municipal Water District, because of the fact, as described above, that reliable records are kept only by the larger concerns. The following table gives the best estimate available of the large consumers.

Table No. 13.—Principal Industrial Water Consumers.

(Average consumption in gallons per day for calendar year 1912.)

	Total Consumption	Private Wells	Peoples Water Co.
Standard Oil Company	1,000,000	500,000	500,000
California Wine Association (Winehaven)	333,000	.....	333,000
Santa Fe Railway	100,000	100,000	.....
Slaughter House at County Line	57,000	57,000	.....
Sunset View Cemetery	55,000	55,000	.....
Stauffer Chemical Works	45,000	45,000	.....
Pullman Shops	36,700	26,700	10,000
Richmond City	12,800	.....	12,800
Metropolitan Match Works	10,000	10,000	.....
San Francisco Quarries Company	5,300	.....	5,300
Hutchinson Quarry	8,300	8,300	.....
Healy-Tibbitts	2,000	.....	2,000
Bates Stege Quarry	6,000	6,000	.....
Pacific Porcelain Company	8,000	8,000	.....
Pacific Sanitary Company	8,000	8,000	.....
California Cap Company	8,000	8,000	.....
Los Angeles Pressed Brick Company	3,200	.....	3,200
Berkeley Steel Works	400	.....	400
Ludwig's Market and Harbor Creamery	665	.....	665
San Francisco-Oakland Terminal Railways	3,540	*1,670	1,870
Western Pipe and Steel Works	3,800	.....	3,800
Southern Pacific Company	2,600	.....	2,600
Abbott Hospital	1,500	500	1,000
Enterprise Brewing Company	300	.....	300
Totals	1,711,105	834,170	876,935

The estimated total production of water within the boundaries of the dictrict with a rough segregation of the disposition made, whether used for domestic or industrial purposes within the district, or piped outside of the district, is shown in the following Table No. 14. The totals of consumption and production for manufacturing or industrial uses as shown in Tables Nos. 13 and 14 are determined from different data and hence the agreement is as close as could be expected.

Table No. 14—Production and Use of Water in Gallons Per Day.

Average (for calendar year 1912).

Source	Production	Manfg.	Domestic	Outside Districts.
Private wells (about 250)	533,500	.....	533,500	.....
Factory wells (inc. W. San Pablo L. & W. Co.	771,500	771,500	.....	.....
Hercules Water Co.	130,000	.....	.....	130,000 to Pinole
H. F. Brown, McEwen Bros., Fred Meyers	39,000	.....	39,000	.....
Peoples' Water Co.—San Pablo No. 1, San Pablo No. 2, San Pablo Creek Wells, Richmond Pumps	1,396,430	882,260	271,670	242,500 to Berkeley
Wild Cat Creek Wells	312,600	.....	.....	312,600 to Berkeley
Sunset View Cemetery	55,000	55,000	.....	.....
Union Water Co.	150,000	1,540	148,460	.....
Totals	3,388,030	1,710,300	992,630	685,100

Total for consumption in district, 2,702,930 gallons.

*From Union Water Company.

Total consumption in district per capita in 1912, $\frac{2,702,930}{13,900} = 194$ gals. per day.

Consumption per capita for manufacturing, $\frac{1,710,300}{13,900} = 123$ gals. per day $= 63.4\%$.

Consumption per capita for domestic use, $\frac{992,630}{13,900} = 71$ gals. per day $= 36.6\%$.

	Per Cent Total Production	Per Cent Consumption in District
Total production of factory and private wells, 1,360,000 = 98 g. p. c. p. d. = ...	40%	50%
Total production of public water companies, 1,342,930 = 97 g. p. c. p. d. = ...	40%	50%
Total production to outside consumers, 685,100 = ...	20%	....
Total production from all sources, 3,388,030 = ...	100%	100%

Larger Consumers of Water.

Additional information concerning the use of water by some of the larger consumers is shown by the following:

The Standard Oil Company are practically the owners of the West San Pablo Land & Water Company, which supplies fresh water to them exclusively, the total amounting to about 500,000 gallons per day. They are also heavy purchasers of water from the Peoples Water Company. At the present time water used in their boilers is treated to reduce the amount and hardness of the boiler scale. In addition to their fresh water supply they have an exclusive salt water auxiliary steam condensing system and use about 25,000,000 gallons of salt water per day for condensing purposes. The Standard Oil Company uses a fleet of 32 vessels for carrying oil from Richmond to all parts of the world. These ships are large consumers of fresh water.

The California Wine Association at Winehaven use about 330,000 gallons per day from the Peoples Water Company, principally for washing casks, tubs, etc. They carry a large insurance on stored stock and depend upon the Peoples Water Company for fire protection.

The Pullman Car Shops are large purchasers of water from the Peoples Water Company. They also develop water for their own use by means of wells and two tunnels 35 feet below the surface, one of which is 64 feet long and the other 42 feet long. The quality of the water obtained is better than that purchased from the Peoples Water Company, but neither is satisfactory. All water used for boilers is chemically treated.

The Santa Fe Railroad produces a large quantity of water per day from their own wells which they use at their shops, ferry boats and locomotives. The water is treated for all these purposes.

Daily Consumption per Capita.

It will be seen by referring to the discussion dealing with the estimated population in the District that the population in the year 1912 was 13,900. Dividing the total consumption in the District in 1912—2,702,930 gallons—by the population—13,900 people—a consump-

tion of 194 gallons per capita per day is obtained. Segregating this consumption between manufacturing and domestic uses, it appears that 1,710,300 gallons or 123 gallons per capita, equal to 63.4 per cent. of the total consumption in the district is used for manufacturing purposes, 992,630 gallons per day or 71 gallons per capita per day, equal to 36.6 per cent. of the total consumption in the district is used for domestic purposes. It is of interest to note that the total production of factory and private wells appears to be 1,360,000 gallons per day or 98 gallons per capita per day, equal to 50 per cent. of the total consumption in the district. The total production of the public service water companies is 1,342,930 gallons per day or 97 gallons per capita per day, equal to 50 per cent of the total consumption in the district.

The total production of water in the district is estimated at 3,388,030 gallons per day, or 244 gallons per capita per day. Ninety-eight gallons per capita per day or 40 per cent of the total production is credited to factories and private wells, 97 gallons per capita per day or 40 per cent of the total production is credited to the public water companies within the district and 49 gallons per capita per day, or 20 per cent of the total production, is pumped outside of the district to Hercules and Berkeley.

INFLUENCES AFFECTING CONSUMPTION PER CAPITA.

Increasing Consumption.

For many years throughout the United States there has been a steady increase in water consumption. This is due in a great measure to the higher standards of cleanliness which have gradually developed in every branch of life, to the introduction of conveniences and fixtures for the use of water, and to the growing appreciation of its value for sanitary uses. Omitting any cases of excessive rates of increase, in typical American cities, there still remains a marked tendency towards an increased consumption of water. The introduction of meters and efficient systems of inspection of consumption in nearly every case results in a sudden decrease in the consumption of water per capita, but immediately the rate again begins to increase. An approximation of the amount of this annual increase would be about a gallon per capita per day. The difficulty of closely estimating this feature is very great, but normally it approximates the figures given.

Tabulation of Factors Affecting Consumption per Capita.

1. Number of private supplies.
2. Wealth and habits of people.
3. Introduction of a publicly-owned supply.
4. Percentage of taps metered.
5. Abundance.
6. Pressure.
7. Quality.
8. Leakage.
9. Waste.
10. Irrigation of lawns.
11. Sprinkling of streets, sewer flushing.
12. Fire protection.
13. Increase in population.
14. Industrial development.
15. Climatic conditions.

The effect of each one of these factors upon the consumption per capita will be considered concisely, and where possible, figures will be given to state the effect quantitatively. In general, however, it is not possible to even approximate the effect in actual figures.

Effect of Private Supplies.

As shown in detail in Chapter No. V, it seems probable that the underground sources of water supply in the district have already been developed to their full capacity. The principal producer of underground water is the Peoples Water Company, which has a large main from its Richmond and San Pablo wells to the larger cities south, where there is urgent demand for all the water that it can supply. Much of the remaining well water used in large industrial establishments is too hard to be satisfactory, requiring chemical treatment before use for steam production. Private wells designed for domestic supply are certain to become contaminated as the population increases, and hence their use for this purpose will be gradually abandoned. It can well be assumed that the limit of water furnished by private supplies has already been reached. It is highly probable that the amount of water consumed in Richmond from this source will decrease in the future because of its being diverted elsewhere, and because large industrial establishments will prefer the soft water to be furnished by the District, to their own well supply of harder water.

Effect of Wealth and Habits of the People.

The standard of living in a community has a very important influence upon the amount of water used. The greater the wealth and culture of the people the greater is the consumption of water for all purposes.

In communities where the majority of the people have comfortable incomes, and are engaged in pursuits permitting of a satisfactory standard of living the water consumption is very much larger than in crowded and tenement districts. The convenient transportation and large area available for residence purposes in Richmond makes it probable that in the future there will be few congested residence sections and hence that the per capita water consumption for domstic purposes will be materially greater than is usual in industrial cities.

Effect of the Introduction of a Publicly Owned Supply.

It is the usual experience that a change from a privately owned water supply to one publicly owned and operated by the municipality, tends to increase the per capita consumption. The quality of the water is usually improved and as the plant is not operated for profit, the rates are usually decreased, both of these factors encouraging a more liberal use of water. The increased interest taken by the citizens in a supply in which they are directly interested also seems to tend to increase their use of the system.

Effect of the Introduction of Meters.

The introduction of water meters always has a very marked effect upon decreasing the per capita consumption. It is probable that the effect is immaterial on the legitimate use of water, the decrease shown

being accounted for by the elimination of useless waste and extravagant use.

The method of paying for water as measured is very much more satisfactory to both buyer and seller and the proper adjustment of rates thus made possible should encourage the legitimate use of water.

The installation of meters in the Oakland Division of the Peoples Water Company up to a percentage of 97 in the year 1910 decreased the consumption of water from 19,457,687 gallons to 17,308,121 gallons, or about 11 per cent of the total consumption.

Effect of Abundance of Supply.

The effect of an ample supply is to enable rates to be fixed at the lowest possible rate, thus encouraging the use of water. It should also have an important effect in inducing industrial concerns to enter Richmond with the knowledge that the water supply will always be ample for their needs.

Effect of Pressure.

The effect of a satisfactory pressure on a distribution system is to increase the amount of water used. Irrigation and lawn sprinkling can be accomplished more quickly and satisfactorily, and water for any purpose can be more readily supplied. When taps are accidentally left open, the amount of water used or wasted will be greater the higher the pressure. The increased waste of water thus caused is largely offset by the saving of time and increased convenience to the consumer.

Effect of Quality of Supply.

Water of good quality will encourage a normal use. As a factor in the increase of consumption a poor quality of water having a negative effect is very noticeable. People accustomed to a fair quality of water will probably not use an increased quantity if the quality is bettered, but they will cease using the water to a large extent if there is a decrease in the quality and will resort to the use of artificial beverages, spring waters, etc.

The effect of furnishing a softer water will greatly encourage the use of water for industrial purposes and to a lesser extent for domestic use.

Leakage.

The physical condition of the distribution system of public water supply determines the amount of leakage which takes place. In new systems well constructed, the leakage should be negligible and in old systems or in systems poorly designed, and hastily constructed, the leakage is liable to be considerable. In some extreme cases it has far exceeded the legitimate use.

Waste.

The actual waste of public water supply is largely dependent upon several of the factors above mentioned, such as the number of meters in use, the pressure at the house taps, the quality and the standard of liv-

ing of the people. All of these factors combine to vary the use of water above the amount actually necessary.

In freezing climates a large element of waste is occasioned by letting water run to prevent the pipes from freezing. This condition, of course, will never occur in Richmond.

Sprinkling of Grounds.

In a city such as Richmond, having a good soil, and an equable climate, and a high percentage of privately owned dwellings, it is probable that there will be a large consumption of water for sprinkling gardens, lawns and shrubbery. This use has not developed very much in Richmond at the present time, on account of the fact that the people have only recently established their homes, but from now on it is probable that the growth of garden lawns and shrubbery will be more common.

In many parts of Richmond the water supply is so poor, and the pressure so low, that it is impracticable to use water for irrigation. The substitution of a water supply at good pressure should greatly increase the per capita consumption for this purpose.

Sprinkling of Streets, Sewer Flushing, Etc.

On account of the improvement in dustless pavement construction in recent years, it is probable that the use of water for street sprinkling will decrease as time goes on. There will be a large use of water, however, for cleaning the streets, rather than for laying the dust. Cities having abundant water supplies very often clean their streets more by washing with a flood of water than by sweeping machines, because the method is more sanitary and the thoroughness of cleaning greater.

Richmond as a whole has sufficient slopes to permit the sewers being constructed so as not to require artificial flushing with water from the mains, except for occasional flushing at dead ends.

Fire Protection.

The supply of water for fire protection not being essential to an estimate of future consumption it has been treated separately in Chapter No. 4. The total amount of water used for fire protection is very small. The maximum rate, however, which may be required for this purpose exceeds the demands for all other purposes combined, although this requirement is only for short periods.

Industrial Development.

As shown by Table No. 14, five-eighths of all the water at present used in the Richmond District is credited to industrial works. This condition will probably continue for several years in the future, and in comparison with other western cities the proportion so used will always be abnormal. At the same time an easily developed underground water supply will tend to decrease the demands for water for industrial use from the public system, wherever the hardness of the water is not a serious objection. It is hardly possible, however, that the present very high per capita consumption of water for industrial purposes can continue as the city grows.

Climatic Conditions.

The result of the remarkably small variation in temperature in Richmond is to cause a more uniform use of water for domestic, public and industrial purposes than would otherwise occur. There is a minimum difference between the mean and maximum rates of water consumption and hence it is unnecessary to provide for more than a comparatively small overdraft. The danger of freezing so common in cities where low temperatures are occasionally prevalent, does not occur in Richmond and hence it is unnecessary to lay the distribution system below the frost line or to provide excess capacity occasioned by water waste to prevent pipes from freezing.

FORECAST OF FUTURE WATER CONSUMPTION.

Method of Forecasting.

In a general way the two methods of forecasting future population previously described can also be applied to a forecast of the probable future water consumption, that is, first by a comparison with other cities similar to Richmond, and second, by the study of the present consumption in Richmond and the influences affecting the increase in water consumption there.

Method No. 1—By Comparison With Other Cities.

Several cities similar to Richmond have been chosen as the most reliable upon which to base an estimate of the probale consumption of the Richmond District. These are tabulated in the following Table No. 15:

Table No. 15—Water Consumption in American Cities—Consumption in Gallons Per Capita Per Day.

City	1912	1911	1910	1909	1906	1900	1890
Baltimore	....	—115	*115	....	....	*111	*94
Buffalo	....	....	*313	....	—322	*234	*186
Birmingham	....	....	*123	....	....	....	*200
Boston	....	....	*130	....	....	....	....
Chicago	....	....	*232	—230	....	*189	*137
Cleveland	....	—104	*101	....	....	*168	*106
Cincinnati	....	—127	*125	....	....	*115	....
Denver	....	—213	*223	....	....	*235	*89
Detroit	....	....	*184	....	....	*153	*144
Duluth	....	....	*90	....	....	*95	*70
Grand Rapids	....	....	*142	....	....	*135	*73
Hartford	....	....	*68	....	....	....	....
Jersey City	....	....	*169	....	....	*142	*148
Kansas City	....	....	*98	....	....	*60	....
Louisville	....	....	*99	....	....	....	....
Memphis	....	....	*103	....	....	*88	....
Minneapolis	....	....	*74	....	....	*93	*78
Milwaukee	....	—112	*114	....	....	*83	*109
Nashville	....	....	*112	....	....	*140	*138
New York	....	....	—120*119	....	....	*121	*95
New Orleans	....	....	*274	....	....	....	....
Philadelphia	....	—210	*203	....	....	*221	....
Pittsburg	....	....	*274	....	....	....	....
Providence	....	....	*63	....	....	*54	*48
Portland, Or.	....	—86	*83	....	....	....	*203
Rochester	....	....	*91	....	....	*85	*62

*Chittenden Report. —Freeman Report.

Table No. 15 (continued).

City	1912	1911	1910	1909	1906	1900	1890
Seattle	....	....	*100	....	....	*70	....
St. Paul	....	....	*60	....	....	*45	....
Spokane	....	....	*287	....	....	*215	....
St. Louis	....	—118	*110	....	....	*110	*73
Washington	....	—178	*180	....	....	*210	*73
Salt Lake City	—243	....	....	....	....	....	....
Colorado Springs	....	—202	....	....	....	....	....
California—							
Pasadena	....	—127	....	....	....	....	....
Los Angeles	....	....	—130*140	....	....	....	....
San Diego	—104	....	....	....	....	....	....
San Francisco	....	‡84	—100 *85	....	....	*75	....
Oakland,Berkeley,etc.	....	....	—114	....	....	....	....
Palo Alto	—90	....	....	....	....	....	....

The above figures are taken from the following reports on the water supply of San Francisco:

The rate of increase in consumption per capita due to the causes which have been enumerated and discussed at the beginning of this chapter has been variously estimated by eminent authorities on water supply, as from 5 to 10 gallons per capita per decade, or ½ gallon to 1 gallon per capita per day yearly.

It is assumed that the new district distribution system will be fully metered when first installed and that the consumption of water for domestic purposes will increase at the rate of 1 gallon per capita per day yearly. The abnormally large percentage of water consumed (63.4 per cent) used for manufacturing in the Richmond District is assumed to decrease resulting in a decrease in total per capita consumption to a minimum of 150 gallons per capita daily in 1955.

In the report of John R. Freeman on the "Water Supply of San Francisco," page 78, the consumption estimated by Engineer C. D. Marx for the year 2000 in Alameda County and Contra Costa County is given as 130 gallons per capita daily for the east bay cities. The consumption in 1910 for the same cities is 114 gallons per capita daily, 80 gallons supplied by the Peoples Water Company and 30 from private supplies. On page 79 of the same report the consumption in San Francisco is given as 100 gallons per capita daily, 85 supplied by the Spring Valley Water Company, 13 from private wells, and 2 from the Golden Gate Park Wells.

In the report of Charles Gilman Hyde, on a Proposed Filtered Water Supply for the City of Sacramento, dated 1909, on page 23, the estimated daily consumption for Sacramento is assumed to increase one-half gallon per capita per day yearly after a fully metered system is attained in the year 1930.

Method No. 2—Forecast From Study of Present Conditions.

A number of arbitrary assumptions must be made in order to estimate by a study of present conditions the changes in future per capita consumption. In preparing the following tables, it is assumed that the distribution systems of the Water Companies now supplying water in this district will be at once absorbed or that the district by paralleling their mains and furnishing a better supply of water at a high pressure

‡Spring Valley Report. *Chittenden Report. —Freeman Report.

will soon get the bulk of their customers, and that the source of supply from the Sacramento River recommended by this report is adopted and developed substantially as described in Chapter VII.

It is also assumed that the consumption of water from private wells will decrease when the new system is put into operation, because of the large industrial concerns using the softer water to be furnished by the district, and because of the probable diversion into Berkeley and Oakland of well water produced by the Peoples Water Company.

With a steady growth of population, however, the use from private wells will again steadily increase up to the maximum yield of the district.

It is probable that the most marked change in the per capita consumption will be the sudden increase immediately following the introduction of the new system and continuing during the first few years of its use. With the introduction of a municipally owned system furnishing better pressure and at a cheaper rate, a more liberal use of water will be encouraged and the per capita consumption will steadily rise until the residents have adjusted themselves to the new conditions. After the first short period of rapid increase the rate of increase will sharply decline for the next few years until about 1922, the maximum rate of consumption of 230 gallons per capita will have been reached.

At about this year the limit of capacity of portions of the water system described in Chapter VII will be approached. In order to defer the enlargement of the plant for a few years an effort will probably be made to curtail the extravagant use of water engendered by the construction of a first-class water supply and delivery at cheap rates in a community which previously had suffered for adequate service. The people having become accustomed to the new supply will also naturally use less water after the newness of the system has worn off.

The relative growth of the residence portion of the city with respect to the manufactures will also materially reduce the per capita consumption. The ratio of men employed in manufactories to the total population is much larger at present in Richmond than in similar American manufacturing cities. It is, therefore, reasonable to suppose that the residence portion of the city will develop more rapidly than the manufactories until a normal ratio exists. Examining table No. 14, it is seen that at present about 63 per cent. of the total consumption is for manufacturing purposes. With the population increasing with respect to the manufactories the per capita consumption will, therefore, decrease.

It is estimated that these influences will combine to reduce the per capita consumption from its maximum of 230 gallons per capita in 1922 to 150 gallons per capita in 1950.

On these different assumptions the tables Nos. 15, 16 and 17 showing the predicted per capita consumption, and total consumption have been prepared. The total consumption shown in Table No. 17 is obtained from the per capita consumption from the previous table, and the estimated mean population as given in Table No. 12.

Table No. 16—Forecast of Future Population and Water Consumption.

Year	Population	Consumption g. p. c. daily from Districts System	Consumption g. p. c. daily from public Corporations Etc.	Consumption g. p. c. daily from private wells and Factory wells	Total Consumption g. p. c. daily
1913	15,585	...	196	98	194
1914	17,470	100	25	84	209
1915	19,470	200	...	24	224
1916	21,600	201	...	24	225
1917	23,850	202	...	24	226
1918	26,160	203	...	24	227
1919	28,600	204	...	24	228
1920	31,015	205	...	24	229
1921	33,250	205	...	25	230
1922	35,600	199	...	25	224
1923	37,875	193	...	25	218
1924	40,050	187	...	25	212
1925	42,100	183	...	25	208
1930	53,950	164	...	25	189
1935	66,450	152	...	25	177
1940	81,000	141	...	25	166
1945	96,750	136	...	25	161
1950	115,000	130	...	25	155
1955	134,000	125	...	25	150

Estimated total possible average yield of underground waters, 6,200,000 g. p. d.
Probable future amount of underground waters used in district, 3,350,000 g. p. d.

Table No. 17—Total Daily Consumption in Dist. and From Public and Private Sources.

Year	From District System	From All wells and Public Systems	Total in District	District Sale to Outside Customers	Total Required Capital of District System
1912	.....	2,703,000	2,703,000		
1913	.....	3,025,000	3,025,000		
1914	1,747,000	1,903,000	3,650,000	Not capable	Dependent
1915	3,894,000	466,000	4,360,000	of estimating	on previous
1916	4,340,000	518,000	4,858,000	at the present	two columns
1917	4,820,000	572,000	5,392,000	time	
1918	5,310,000	628,000	5,938,000		
1919	5,840,000	686,000	6,526,000		
1920	6,360,000	744,000	7,104,000		
1921	6,820,000	832,000	7,652,000		
1922	7,086,000	890,000	7,976,000		
1923	7,310,000	947,000	8,257,000		
1924	7,490,000	1,001,000	8,491,000		
1925	7,705,000	1,052,000	8,757,000		
1930	8,850,000	1,348,000	10,198,000		
1935	10,100,000	1,660,000	11,760,000		
1940	11,420,000	2,024,000	13,444,000		
1945	13,160,000	2,417,000	15,577,000		
1950	14,950,000	2,878,000	17,828,000		
1955	16,750,000	3,350,000	20,100,000		

The above table will be used as the basis for designing the capacity of the water system and predicting probable future water rates.

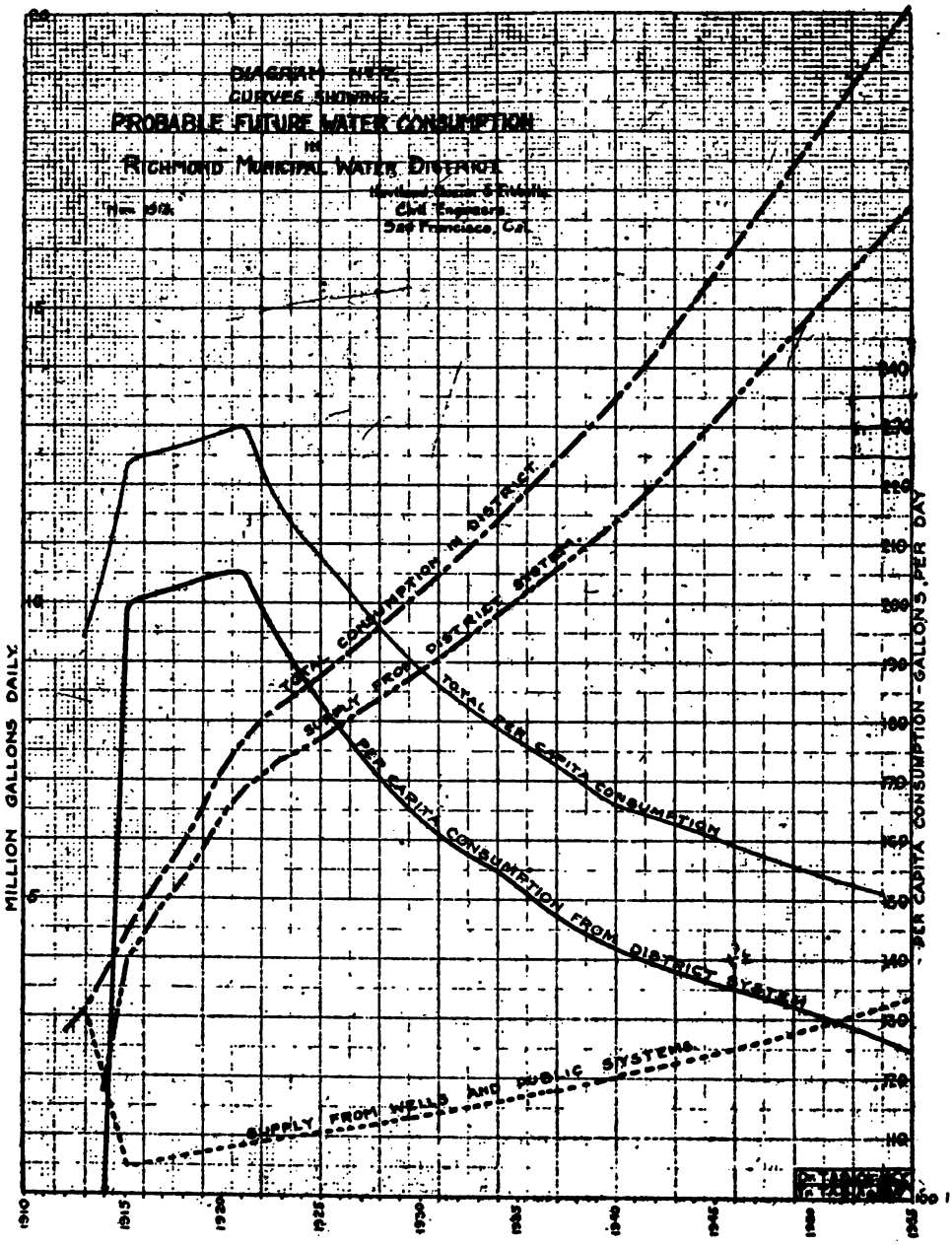


DIAGRAM NO. 2
CURVES SHOWING
PROBABLE FUTURE WATER CONSUMPTION
IN
RICHMOND MUNICIPAL WATER DISTRICT
Hyatt Conn. & Tibbits
Civil Engineers
San Francisco, Cal.
Nov. 1913.
MILLION GALLONS DAILY.
PER CAPITA CONSUMPTION - GALLONS PER DAY
TOTAL CONSUMPTION IN DISTRICT.
SUPPLY FROM DISTRICT SYSTEM.
TOTAL PER CAPITA CONSUMPTION
PER CAPITA CONSUMPTION FROM DISTRICT SYSTEM
SUPPLY FROM WELLS AND PUBLIC SYSTEMS.
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960

CHAPTER No. III.

Present Water Supply of District

Wells.

All of the water now being used in the Richmond Municipal Water District is derived from underground sources. The supply is pumped from wells located in the Valley of San Pablo Creek, in the gravel cones of San Pablo and Wild Cat Creeks, and in the marginal plain between the base of the hills and the shore line. The total production from the wells will probably average from 3 to 4 millon gallons per day. Excluding the non-productive and small private wells, there is a total of about 350 operative wells in the district. Two hundred and forty of these are private wells, the balance belonging to concerns engaged in the business of retailing water. Fifty-five are the property of the Peoples Water Company and 25 of these are located in the Valley of San Pablo Creek. Sixteen are the property of the West San Pablo Land and Water Company, supplying water exclusively to the Standard Oil Company. Thirteen are the property of the Union Water Company. Seven are the property of the Santa Fe Railway Company. Six are the property of the Sunset View Cemetery Company. Four are the property of McEwen Brothers. Three are the property of Fred Meyers. Three belong to the Hercules Water Company, supplying the powder works at Pinole. One is the property of H. F. Brown.

Reservoirs.

There are three reservoirs in the District. The Peoples Water Company have a reservoir with a capacity of 1 million gallons. located at an elevation of about 180 feet, on the Potrero Hills, in the western end of Richmond. The Santa Fe Railway has a small reservoir at the summit above the Santa Fe tunnel through the Potrero Hills at an elevation of about 200 feet. The Sunset View Cemetery has a reservoir with a capacity of 1 million gallons, at an elevation of 450 feet. With the exception of these three reservoirs the water companies have no considerable storage capacity. Dependence is placed upon small tanks, usually built on some slight elevation.

Pumping and Distributing Equipment.

All sorts of pumping equipment are used in connection with the many wells. Power is supplied by electricity. steam, or gasoline engines. Water is distributed through a number of different systems which are entirely separate. The larger portion of the supply is furnished by the Peoples Water Company from a distribution system of pipes, 2, 4, 6 and 12 inches in diameter, feeding from a 24-inch main, running from San Pablo Station No. 2 through the City of Richmond, and down Potrero and San Pablo Avenues to Berkeley. The distribution systems of the other water companies are in general of limited area and composed of small pipe. Plate No. 2 shows, in a general way, the areas served by each of the various water companies and the size and

location of pipes. From this map it will be readily seen that the distribution systems are quite inadequate, except for limited zones of business property along Macdonald Avenue and at Point Richmond.

Diversion Outside of District.

All of the water produced in the District is not being consumed there. The Hercules Water Company is pumping from wells in the San Pablo cone to supply the powder works at Pinole, just north of the District boundary line. The Peoples Water Company is developing water from wells near the head of Wild Cat Creek, which is being diverted into Berkeley, and during most of the year a portion of the main supply of the Peoples Water Company, from the San Pablo and Richmond wells, is being pumped back into Berkeley. At times, however, this latter condition is reversed, and water is pumped into Richmond from Berkeley. The total amount produced in the District and diverted elsewhere is approximately as shown by Table No. 14 of the preceding Chapter.

PEOPLES WATER COMPANY PLANT AT RICHMOND.

The data concerning the Peoples Water Company in Richmond has been obtained, chiefly, from the records of the Company, and from information furnished through the courtesy of Chief Engineer Wilhelm.

Sources of Supply.

Excluding the wells at the head of Wild Cat Creek, which do not supply Richmond, the Peoples Water Company derives its supply from five groups of 10-inch and 12-inch wells. Two of these are in the Valley of San Pablo Creek, one near the upper end of the San Pablo Creek cone, at the foot of the hills, one near the mouth of San Pablo Creek, immediately west of the Southern Pacific Railway, and one along the Oakland branch of the Santa Fe Railway in the City of Richmond, between First and Sixteenth Streets.

San Pablo Creek Wells.

Along the Valley of San Pablo Creek there is one 10-inch well, six 12-inch wells and eighteen 14-inch wells, a total of 25. The estimated capacity is about 300,000 gallons per day. The wells are strung out along the axis of the narrow valley near the creek. They vary in depth from 50 to over 200 feet. Twenty-three of them are over 50 feet in depth, 3 are over 100 feet and 2 are over 200 feet in depth. These wells were connected up in August, 1912.

The San Pablo Creek wells are pumped by single, isolated pumps, operated by electricity furnished from the Bay Counties Power line of the Pacific Gas and Electric Company. They deliver water into a gravity flow 12-inch main, laid approximately on a hydraulic gradient along San Pablo Creek, and discharge into the San Pablo pumping station No. 1. The main is a steel riveted pipe of 12-inch No. 14 gauge, and 14-inch No. 16 gauge. In general, feed pipes from the wells to the main serve 1 or 2 wells. In one case, two wells and a spring are on a 4-inch pipe, and in another case 3 wells are on an 8-inch pipe at the

head of the 12-inch main. All other feed pipes are 2, 3 and 4 inches in diameter.

At the upper end of the pipe line an intake is provided to receive water direct from San Pablo Creek. Water from this source, however, is available only during high stages of the creek, at such times as the water is not too muddy.

San Pablo No. 1.

These wells are located at the old town of San Pablo on a 25-acre tract of land, between San Pablo Creek on the north, and Wild Cat Creek on the south. This tract has a length of about 1 mile, parallel to the general direction of the creeks. At the eastern end of this property the creeks are about ¼ of a mile apart and at the western end about ¾ of a mile apart. The general elevation of the tract is about 60 feet above sea level. There are 10 wells in the group, 9 of which are in operation. About one-half of these wells were bored in 1906, and the remainder in 1910-11. They are 10 inches in diameter, and range in depth from 134 to 359 feet.

The Peoples Water Company estimate their capacity at 550,000 gallons per day. The actual production in the 5-year period of 1907 to 1911 is given as 635,552,409 gallons or about 348,000 gallons per day. The maximum years average in 1907 was 527,000 gallons per day and the minimum in 1910 was 290,000 gallons per day.

The water is forced from these wells by compressed air to the San Pablo No. 1 pumping plant, consisting of one Smith-Vaile triplex 7x8 inch pump; capacity 400,000 gallons per day, and one Gould triplex 6½x8 inch pump; capacity 300,000 gallons per day. Both are electrically driven. The first is about 11 years old and the second about 2 years old. The water is pumped through a 12½-inch riveted steel pipe directly into the Richmond Distributing system and Richmond reservoir. By opening a gate this station can be connected with a 24-inch force main, leading from San Pablo No. 2 pumping station to Berkeley.

San Pablo No. 2.

This source of supply comprises eleven 10-inch wells, from 265 to 510 feet in depth. They are located at the edges of the marsh land near the shore of the Bay, about one-half mile north of the San Pablo station of the Southern Pacific. They are strung along near the west side of the Southern Pacific right of way for a distance of about 2800 feet, northerly from San Pablo Creek. The surface of the ground is at elevation 15 to 24 feet above sea level. The wells are bored through the delta of San Pablo Creek near its upper end. Nine of them were driven in 1907. All are in operation. The depth of the deeper wells at San Pablo No. 2 is as follows:

1—510 feet.	1—471 feet.
1—497 feet.	1—412 feet.
1—491 feet.	1—295 feet.
1—477 feet.	1—266 feet.

The San Pablo No. 2 wells are now classed by the water company as part of the Berkeley system. This is because under a ruling of the Railway Commission, the Richmond, Berkeley and Oakland systems are now operated as one plant, instead of being operated separately as heretofore by crediting or debiting a draft from one to the other.

Richmond Wells.

This is a group of seven 10-inch wells, from 115 to 203 feet deep. They are located in the City of Richmond, north of, and adjoining the Oakland branch of the Santa Fe Railway. They are about ¾ of a mile from the shore of the Bay and 2 miles southwest of Wild Cat Creek, between Ohio, Chanslor, Second and Seventeenth Streets. The general elevation of the tract is about 10 feet above sea level. Water is forced from the wells by compressed air to the Richmond pumping plant, where there are three triplex pumps, belt driven from gasoline engines, the combined capacity being 875,000 gallons per 24 hours. These pumps force the water into the Richmond Distributing system and the Richmond reservoir. The capacity of these wells is estimated by the Water Company at 500,000 gallons per day. In the 5-year period 1907-1911, the average yield was 306,000 gallons per day. The maximum in 1910 was 348,000 gallons per day, and the minimum in 1909 was 289,000 gallons per day.

Wild Cat Wells.

These wells are near the head of Wild Cat Creek where the County Road from Berkeley to Orinda Park crosses the Creek. They are about 2½ miles northeast of the Berkeley City Hall, and two-thirds of a mile northwest of Grizzly Peak, and are close to the extreme south corner of the Richmond Municipal Water District. Within a small area there are 11 bored wells, from 100 to 250 feet in depth, and from 6 to 10 inches in diameter. There are also 2 new 12-inch wells, 275 and 293 feet deep. These wells penetrate several strata of mixed clay and boulders and a few strata of fine gravel. The majority of these have the water surface very near the top. The flow is increased by compressed air, furnished by a small compressor driven by a gasoline engine. Four of the wells were bored in 1911. There is also an 800-foot tunnel, driven through the rock which, however, develops water only in the first 200 feet. During certain seasons, water is also diverted from Wild Cat Creek. The wells, tunnel and creek diversions are all connected up by pipes to a small brick receiver with a capacity of 15,000 gallons located at elevation 950. From the receiver the water is conveyed by 2 lines of riveted iron pipes 7 inches and 9 inches in diameter, to the Summit Reservoir 1½ miles distant, on the top of the ridge between Alameda and Contra Costa Counties. The average yield during the 10-year period, 1902-1911, was about 413,000 gallons per day. The maximum yearly output in 1906 was about 599,000 gallons per day, and the minimum in 1902, 283,000 gallons per day. None of this is used for Richmond.

Total Yield in 1902-1912.

The total yield of water from sources of the Peoples Water Company during the years 1902-1912 is shown by the following Table:

Table No. 18—Average Yield of Water in Millon Gallons Per Day From People Water Co., Richmond Sources, 1902-1912.

Year	Wild Cat Wells Gals.	San Pablo No. 1. Gals.	San Pablo No. 2. Gals.	Richmond Wells. Gals.
1902	103,305,700	.....	.....	.....
1903	145,023,000	.....	.....	.....
1904	147,197,000	.....	.....	.....
1905	120,739,400	.....	.....	.....
1906	218,372,800	.....	.....	.....
1907	178,223,800	151,142,340	.....	98,762,315
1908	124,505,800	137,322,100	233,049,320	113,167,058
1909	191,797,000	124,953,598	339,953,738	105,335,360
1910	107,517,900	105,943,689	219,006,821	127,103,989
1911	172,051,100	116,190,682	215,352,027	115,037,220
Total	508,733,500	635,552,409	1,007,261,906	559,405,942
Average per year	150,873,350	127,110,482	251,815,476	111,881,188
Average per day	413,000	348,000	690,000	306,500

Total daily average, 1,758,500.

1911	San Pablo No. 1		San Pablo No. 2	
Month	Monthly	Daily	Monthly	Daily
January	8,613,216	277,846	23,296,717	751,507
February	3,163,296	112,975	15,306,560	546,663
March	5,316,500	171,500	.....	.....
April	3,109,928	103,664	23,411,510	780,384
May	7,460,204	204,652	22,581,175	728,425
June	12,812,268	427,076	21,042,190	701,406
July	12,387,544	399,660	21,087,130	680,230
August	13,580,634	438,085	20,100,865	648,415
September	8,746,136	291,538	23,857,600	795,253
October	13,069,028	421,582	19,424,910	626,610
November	12,228,540	407,618	18,281,010	609,367
December	11,482,648	370,408	12,003,200	387,200

1911	Richmond Wells		Wild Cat Wells	
January	2,305,760	74,379	31,755,000	1,024,355
February	5,028,160	179,577	16,666,000	595,214
March	7,996,280	257,945	10,949,000	353,194
April	959,320	31,977	9,450,000	315,000
May	7,571,860	244,254	9,676,000	312,129
June	8,929,920	297,664	14,880,000	496,000
July	12,101,000	390,355	13,516,000	436,000
August	14,327,040	462,162	12,617,000	407,000
September	11,516,540	383,885	5,073,000	169,100
October	14,297,240	461,222	13,020,000	420,000
November	8,784,600	292,820	13,901,000	463,560
December	9,072,000	292,645	13,411,100	432,616

1912	San Pablo No. 1		San Pablo No. 2	
Month	Monthly	Daily	Monthly	Daily
January	12,069,036	389,324	633,616	20,439
February	11,906,464	410,568	720,000	24,828
March	12,069,136	389,330	11,599,821	374,188
April	10,522,765	350,759	16,020,928	534,030
May	9,989,235	322,233	16,980,723	547,765
June	10,368,511	345,617	15,347,449	511,582
July	10,113,811	326,252	18,270,000	589,355
August	11,893,382	383,658	14,334,484	462,403
September	15,391,385	513,046	10,142,194	338,073
October	14,885,595	480,181	10,213,224	329,459
November	13,710,991	457,033	8,898,456	296,615
December	16,035,025	517,259	10,418,772	336,089
Totals	148,955,336		133,579,667	

	Richmond Wells		Wild Cat Wells	
January	Not in use		14,272,028	460,388
February	6,640,000	228,966	11,324,500	390,500
March	7,640,785	246,477	13,001,400	419,400
April	10,723,314	357,444	10,128,000	337,600
May	10,117,710	326,380	8,844,300	285,300
June	10,417,850	347,262	8,358,000	278,600
July	14,806,567	477,631	6,987,400	225,400
August	18,647,366	601,528	9,529,400	307,400
September	16,174,816	539,161	9,375,000	312,500
October	16,445,404	530,497	7,982,500	257,500
November	13,860,320	462,011	1,701,000	56,700
December	14,359,680	463,215	13,020,000	420,000
Totals	139,833,812		114,523,528	

	San Pablo Creek.	
August	2,250,000	72,581
September	3,500,000	116,667
October	6,000,000	193,548
November	6,600,000	220,000
December	7,128,000	229,936
Total	25,478,000	.....

DISTRIBUTION SYSTEM.

Reservoirs.

The Peoples Water Company has no storage reservoirs within the limits of the Water District. They have one distribution reservoir on the crest of the Potrero Hills, in the City of Richmond, about one-half mile northwest of the Santa Fe tunnel. This reservoir, which has a capacity of one million gallons, is at elevation 200 above sea level. It acts as a balancing and distributing reservoir, supplied by the

pumping plants, particularly San Pablo wells No. 2 and the Richmond wells, which pump direct against the distribution system, and the reservoirs. The floors and walls are lined with concrete, and the reservoir is covered with a wooden roof, and the whole is in excellent condition.

Area Supplied.

The Peoples Water Company supplies about 90 per cent. of the water consumed in Richmond which is sold by companies organized for the production and sale of water for general use. The area covered by their distribution system, as shown on the accompanying map, Plate No. 2, comprises three distinct centers. Two of these, one at West Richmond and one along Macdonald Avenue, include all of the thickly built-up sections of the city and the retail business districts. The third is toward the southern edge of the district, in the vicinity of Stege and Rust and consists of a good residence district with rolling surface and scattered improvements. Practically all of the West Richmond District lying along the base of the Potrero Hills, and all of the business portion of the district lying along Macdonald Avenue in the triangular area between the three railroad tracks, is supplied by the Peoples Water Company. They also have lines running out to the California Wine Association, and down Pullman, Potrero and San Pablo Avenues, through Pullman, Stege and Rust. The total area supplied is approximately as shown by the following table:

Table No. 19—Areas in Richmond Water District Supplied by Peoples Water Co.

	Acres
West Richmond Section	100
Macdonald Ave. Section, between and adjacent to railroads	640
Southern Section, including—	
Small tract to the east of Stege	40
Tract near Rust and east of San Pablo Ave	140
Tract near Rust and west of San Pablo Ave., including Richmond Annex	230
Total	1,150

Growth of Peoples Water Company.

The growth of the distribution system of the Peoples Water Company in Richmond can best be shown by the following table, giving the total number of services recorded in the Richmond division, the first of each of the last seven years:

Table No. 20—Increase in the Number of Services of the Peoples Water Company in Richmond Division.

Date	Richmond Division
January 1, 1907	652
" 1908	1,112
" 1909	1,458
" 1910	1,651
" 1911	1,922
" 1912	2,262
" 1913	2,458

Water Mains.

The Peoples Water Company has a 12 and 14-inch riveted steel pipe along San Pablo Creek from the San Pablo Creek wells to San Pablo Pumping Station No. 1. There is a 12½-inch riveted steel pipe from San Pablo Station No. 1 down 23rd Street to Macdonald Avenue, thence to 10th Street, to Ohio, to Railroad Avenue, and to the distributing reservoir on the Potrero Hills. There is a 24-inch riveted steel pipe from San Pablo Pumping Station No. 2 along the east side of the Southern Pacific Railroad to Potrero Avenue, thence easterly along Potrero to San Pablo Avenue and along San Pablo Avenue to Berkeley. This is also cross-connected into the Richmond system. The 12½-inch main from San Pablo No. 1 is of No. 12 gauge riveted steel, under about 80 lbs. pressure. The 24-inch main from San Pablo No. 2 is of three-sixteenths inch riveted steel, under about 80 lbs. pressure.

Distributing Pipes.

The following table obtained from Chief Engineer Wilhelm of the Peoples Water Company shows the principal distributing pipes of the Peoples Water Company in the City of Richmond:

Table No. 21—Water Pipes of the Peoples Water Company in the City of Richmond.

Streets running east and west in triangular area between railroads in main portion of city.

Street	From	To	Size	Direction of flow
Macdonald Ave.	23rd St	10th St.	12½	West
	10th	1st	6	West
	10th	Espee Ave.	6 to 14th	East
Nevin Ave.	16th	C	4	
Barrett Ave.	C	23rd	4	
Ripley Ave.	A	Bet. 8th and 9th	4	
Pennsylvania	10th	2nd	4	
Lucas	6th	Jog in 6th St. line	4	
Lincoln Ave.	2nd	17th	4	
Bissell	19th	Espee	4	
	1st	West	2	
Chanslor	1st	6th		
	170 ft. each way from center line	7th St.	4	
	9th	10th	4	
	14th	15th	4	
Ohio	10th	Railroad Ave.	12½	Normally west East of Peak Load.
	10th	12th	4	East
Streets North and South in "A" portion of Richmond.				
1st	Nevin	Barrett to A.T.S.F.	2	
	Ripley	A. T. & S. F.	2	
	Nevin	Bissell and Bissell to Chanslor	2	
2nd	Barrett	To Pennsylvania	2	
	Barrett	A. T. & S. F.	4	

Street	From	To	Size		Direction of flow
3rd	Barrett	Pennsylvania	4		North
	Ohio	Cutting	2		South
	150 ft. south				
	Barrett	100 ft. N. A. T. & S. F.	2		South
4th	Barrett	150 ft. N. A. T. & S. F.			South
	Barrett	300 ft. N. of Barrett			
5th	Pann, with jog on				
	alley	100 ft. N. Chanslor	2		
	Chanslor	50 ft. N. A. T. & S. F.	2		
Turpin	Alley	250 ft. S. Lucas			
6th	Macdonald	10 ft. N. Chanslor	4		South
	Chanslor	50 ft. N. A. T. & S. F.	2		South
	Macdonald	Lincoln	4		North
	Ohio	50 ft. N. Chanslor	8	c. i.	North
7th	One block north from	Lincoln	2		North
	Barrett	50 ft. N. A. T. & S. F.	2		South
8th	Barrett	Pennsylvania	4		North
	One block north of Lincoln and 250 ft. south from Lincoln.		2		N. and S.
		200 ft. N. Chanslor	2		South
9th	Pennsylvania	250 ft. S. Bissell	2		N. and S.
	Chanslor	20 ft. N. A. T. & S. F.	2		South
10th	Macdonald	Pennsylvania	6		North
	Macdonald	Bissell	4		South
	Macdonald	Ohio	12½		South main to point.
11th	180 ft. S. Barrett	150 ft. S. Bissell	2		N. and S.
	Ohio	300 ft. S. Ohio			
Ohio	80 ft. S. Barrett	250 ft. N. Barrett	2		N. and S.
12th	200 ft. N. Barrett	300 ft. S. Bissell	2		N. and S.
13th	Macdonald	250 ft. N. Barrett	2		North
	200 ft. N. from and 250 ft. S. from	Bissell	2		
14th	Barrett	Chanslor	4		N. and S.
	200 ft. N. of Barrett		2		North
15th	Macdonald	Chanslor	4		South
	250 ft. from Barrett		2		South
	130 ft. S. from Nevin.		2		South
16th	Macdonald	Chanslor	2		South
	180 ft. N. from Macdonald		2		North
17th	380 ft. S. from Bissell		2		South
18th	70 ft. S. Espee		2		South
19th	150 ft. S. Bissell		2		South
20th	Espee	50 ft. Chanslor	2		South
Sunset Ave.	400 ft. southeast from Barrett		2		
7th	Perez Lane	Pennsylvania	2		
Hawthorne	Running west one blk. from 8th		2		
Maple	Running west one blk. from 8th		2		
Elm	Running west one blk. from 8th		2		
Roosevelt Ave.	10th	100 ft E. 11th	4		
11th	Roosevelt	500 ft. north	2		
A	Nevin	Ripley	4		
B	Nevin	Barrett and 150 north	2		
C	Nevin	Barrett	2		

All pipe 4 inches and over is C. I. unless otherwise stated (all pipe in Richmond Annex is black steel screw pipe).

12½ inch is riveted sheet steel pipe. Pipe under 4 inches is black wrought iron pipe. 8-inch sheet steel main connects wells along Oak. Branch of Santa Fe 8 wells deliver into pump and are pumped into 12½-inch main.
Area east of S. P. Railroad.

Street	From	To	Size	Direction of flow
Kearney St.		Clinton	24	South
Clinton	Kearny	20th	4	East
14th	Clinton	100 ft. N. of N. L. of Clinton	2	North
15th	Clinton	200 ft. N. of N. L. of Clinton	2	North
19th	Clinton	150 ft. N. of N. L. of Clinton	2	North
16th	Clinton	320 ft. S. of S. L. of Clinton	2	South
18th	Clinton	Roosevelt	2	South
19th	Clinton	Macdonald	2½ Roose. 2 R. to Mcd.	South
17th	Roosevelt	200 ft. S. Barrett	2	South
20th	Roosevelt	500 ft. N. Roosevelt	2	
	Macdonald	400 ft. N. Barrett	2	
21st	400 ft. N. Barrett	S. P. R. of W. and thence to 22nd St.	2	
22nd	Nevin	200 ft. N. Barrett		
	Macdonald	150 ft. S.	2	
23rd	Macdonald	230 ft. south	2	
	Macdonald	North	12½	Riveted steel pipe
Roosevelt	17th	20th	4	
Nevin	S. P. R. R. of W.	200 ft. E. of 22nd	2	
Bissell	21st	300 ft. E. of E. L. of 21st	2	

24-inch main runs down to Nevin Street, east along Nevin to 21st, south along 21st to S. P. right of way; thence southeasterly.

A summary of the total amount of pipe of each size charged to the Richmond Division is shown by the following table:

Table No. 22—Summary of Peoples Water Company Pipe by Sizes, January 1, 1913.

Size inches	Length feet	Per Cent of total	Per Cent of Total this size or smaller
½	370	.14	.14
¾	2,194	.82	.96
1	1,780	.66	1.62
1½	280	.10	1.72
2	115,009	42.92	44.64
2½	1,200	.45	45.09
3	16,152	6.03	51.12
4	65,848	24.60	75.72
5	1,901	.71	76.43
6	13,663	5.12	81.55
8	17,707	6.62	88.17
10	7,613	2.85	91.02
12½	21,996	8.23	99.25
12	1,995	.75	100.00
Totals	267,708	100.00	.....

Meters and Taps.

The total number of taps and of meters as shown by the Peoples Water Company report of December, 1912, in the Richmond Division, is shown by the following table:

Table No. 23—Taps and Meters in Richmond Service of Peoples Water Company.

Size	¾ in. & ⅝ in.	1 in.	1½ in.	2 in.	3 in.	4 in.	12 in.	Total
Richmond taps	2408	7	7	27	4	4	1	2458
Richmond meters ..	1850	6	7	22	4	3		1892

Pressures.

The maximum pressures throughout most of the distribution system are governed by the relative elevation of the flow line in the reservoir in the Potrero Hills and of the district supplied. The water level in the reservoir is normally maintained at elevation 207 feet, and the bulk of the district supplied is not over 20 to 30 feet above sea level. This gives a maximum static pressure of about 180 feet of head or between 70 and 80 lbs. per square inch. In the Point Richmond section where the ground rises rapidly on the eastern slopes of the Potrero Hills the actual pressures will vary from about 70 lbs. down to 10 or 15 lbs. per square inch. In the eastern portion of the town they will generally vary from 40 to 70 lbs. per square inch.

Fire Protection.

The static head indicated above is not large, and most of the distribution pipes are small so that working pressures at fire hydrants are considerably below those demanded by the underwriters where the lowest insurance rates prevail. In the higher portions of the town the pressures are so low that hose streams are of little value for fire protection, as has been recently evidenced by several destructive fires. In the City of Richmond there are about 100 hydrants supplied by the Peoples Water Company. Most of these are spaced too far apart to conform to the underwriters requirements for the lowest insurance rates. In the distribution system throughout the city the mains are much smaller than required by the underwriters for minimum insurance rates. In the districts outside of the city limits there is no serious attempt to provide any protection from fire.

POSSIBLE IMPROVEMENTS OF THE PEOPLES WATER COMPANY SYSTEM.

Elaborate plans have been made by the Peoples Water Company for largely increasing their sources of supply. In the Richmond District this can be most readily done by storing the surface runoff of Wild Cat, San Pablo and Pinole Creeks. Reservoirs of large capacity can be formed as described in Chapter No. 6 by the construction of earthen dams. No plans for an increase in the number of wells have been made, as the company now has many unused along San Pablo Creek, and

they do not think that the wells which they now own are yet being pumped to their full capacity.

The principal improvements for the distribution system would be increase of pressure over the entire system by the construction of a temporary storage reservoir at a higher elevation than the Potrero reservoir, increase of the size of mains, particularly in the business district, closer spacing of hydrants, and increase of reservoir capacity. There is also great room for improvement in the manner of installing hydrants in the built-up sections of the district outside of the City of Richmond, such as San Pablo, Stege and Rust. Until the last year it has been the policy of the company to make no extensions of their present system within the city except where paid for by consumers. To obtain water the outlying sections must bear the expense of installing pipe for the water company, or sinking wells for their own use. This policy has retarded the development of considerable portions of the city lying beyond the present mains of the company, as it has been impossible to get water for domestic purposes at the ordinary rates charged.

SMALLER WATER PLANTS.

The other water companies operating within the Richmond Municipal Water District are small systems usually supplying industrial establishments or one or two subdivisions with small distribution systems. The principal ones are the Union Water Company, Fred Meyers Water Company, McEwen Brothers Water Company, Herbert Brown Water Company, West San Pablo Water Company, and the Hercules Water Company.

Union Water Company.

Three separate areas are now served by this company, each of them small and sparsely settled. One is an area of about 145 acres at Stege; one an area of about 52 acres west of the Southern Pacific tracks at Pullman, and the other consists of two adjacent areas of about 90 acres each, of the new subdivisions of Macdonald Avenue Civic Center Tract and Grand View Terrace. The company operates a pumping station at San Pablo pumping from a 12-inch well 330 feet deep, equipped with a 3¾-inch by 12-inch double acting deep well pump, gear connected to a 3 horsepower Westinghouse motor in a timber frame pump house. They also operate Pullman stations 1, 2 and 3 with one well each, equipped with pumping machinery and pump house at Pulmman Station. No. 1 is a 20,000-gallon wooden frame tank, on a 40-foot tower. At Pullman Station No. 4 there are seven wells from which water is pumped by a Dean Triplex 4 x 6-inch pump, connected to a 7½ horsepower motor. The company also owns two 20,000 gallon wooden frame tanks in Bay View Park at an elevation of about 100 feet. Most of their wells are surface wells about twenty feet deep. This company also owns the frontage between Mason Street and the east line of Richmond-Pullman, lots 15, 19, 20 and 21 on Wild Cat Creek.

The size of pipe used ranges from 2 inch to 6 inch in diameter. Static pressures employed are 15 to 35 pounds per square inch. The

mains are so small that with any considerable draft on the system the friction losses would greatly reduce these pressures. There is no serious attempt at fire protection, 4-inch mains being the rule with no hydrants, although there are some 6-inch mains in Nichol-Macdonald Avenue, Civic Center Tract and Grand View Terrace. For domestic supply the system could be used, however, with some alterations.

Fred Meyers Water System.

This system supplies two distinct areas, the largest, an area of about 400 acres east and north of the Pullman Car Works, in general lying east of Pullman Avenue, west of San Pablo Avenue, north of Potrero Avenue, and south of Grand View Terrace. This area at present is not very thickly settled, but is rapidly building up. The second area is in Wall's Second Addition to Richmond, containing about 100 acres well toward the northern part of the city, north of the main line of the Santa Fe Railroad, and near the Shrock Furniture Factory. The Pullman System is supplied by pumping from wells about 100 feet deep, into three elevated tanks distributed throughout the territory supplied. The system in Wall's Second Addition is also supplied from a well through an elevated tank. The pipes in the Pullman system are from 1¼ inches to 4 inches in diameter. Much of this is reported to have been second-hand pipe when laid. In the system in Wall's Second Addition much of the pipe is 1¼ inches, the largest being 3 inches. The static pressures will vary from 15 to 35 pounds per square inch. No attempt is made at fire protection other than that furnished from faucets in residences. No hydrants are connected with the system, and the pipes in general are so small that excessive friction losses would reduce the already small head so that hydrants would be useless. Only recently a house was destroyed in this vicinity, it being impossible to obtain water for fire-fighting purposes. Meyers usually makes a contract with the owner of a subdivision or a tract of land to install a system therein, charging a substantial bonus, often 25 to 30 per cent of the total cost of installation, the owner giving him an exclusive right to install the water system on the property covering a period of 5 to 10 years, then when the service connections are made he makes a contract with the individual whereby the individual agrees to take water from him exclusively covering a period of 5 or more years. In the district served by Meyers practically all of the present developments excepting the larger factories procure their water from him and have signed contracts of this nature.

McEwen Brothers Water System.

The area supplied by this system lies south of the Oakland branch of the Santa Fe Railroad between 1st and 16th Streets and between Virginia Street on the south and the Oakland branch of the Santa Fe Railroad on the north, and contains about 220 acres. Water is pumped from 4 wells into tanks elevated about 40 feet above the ground in the neighborhood of 7th and 8th and Maine Streets.

At 1st Street, where the ground elevation is lowest, the static pressure is in the neighborhood of 60 pounds, but at 16th Street,

which is at a higher elevation, the pressure is so low that the water barely runs through the pipes. There are few hydrants in the district, and it is not probable that the system would be of much use for fire fighting—certainly not in the higher or eastern portion of the district.

Herbert F. Brown Water System.

This system now supplies about 40 acres of the Brown-Andrade Tract. Water is pumped from a well to a large elevated wooden tank. The pipes are small, ranging from 1½ to 3 inches in diameter. Static pressures range from 25 to 30 pounds per square inch. There is no attempt at fire protection and with any considerable draught the friction losses in the small pipes would so reduce the available head that efficient streams could not be obtained from hydrants if they were provided. This system, at the present time, is confined to the Brown-Andrade tract, but the owner expresses the intention of extending the system throughout the tracts owned by him, covering an extensive area in the northerly portions of the City of Richmond.

West San Pablo Land & Water Company.

This company supplies water exclusively to the Standard Oil Company. They have twelve wells from 170 to 325 feet deep, located on lot 190 and vicinity, of the San Pablo Rancho. They also have four other wells nearer town. They supply about 500,000 gallons per day of fresh water.

Hercules Water Company.

This company supplies water to Pinole, chiefly to the powder company. About 130,000 gallons per day is pumped from their wells.

UNSATISFACTORY CHARACTER OF PRESENT WATER SUPPLY.

Area Served.

As described in Chapter No. 1, the total area of comparatively level land in the Richmond Municipal Water District below the 200 foot contour is about 17,000 acres, of which about 6,250 acres, or about 37 per cent is now subdivided into city lots. Of this total area, there is no pretense whatever of serving with water more than about 2,290 acres, or 37 per cent of the total subdivided area, as shown by the following table:

Table No. 24—Approximate Areas Supplied With Water—Richmond Municipal Water District.

		Acres.
Peoples Water Company	West Richmond Section	100
Peoples Water Company	Macdonald Avenue Section	640
Peoples Water Company	Southern Section	410
Union Water Co	Stege Section	145
Union Water Co	Grand View Terrace	93
Union Water Co	Civic Center Tract	90
Union Water Co	El Cerrito	52
Fred Meyers	Pullman Section	400
Fred Meyers	Wall's Addition	100
McEwen Bros	Santa Fe Tract	220
Herbert F. Brown	Brown-Andrade	40
Total		2,290

The above areas in general, cover most of the settled portions of the district, and much sparsely settled area as shown by Plate No. 2. However, there are scattering houses over a much larger area.

Difficulty of Making Extensions.

It is very difficult for private water companies to provide extensions desired. Improvements are scattering and houses and grounds are seldom large enough to furnish large consumers. This has resulted in the necessity of considerable outlay for extensions to distribution systems with small return per unit of length of pipe. This condition particularly makes it impossible to provide pipes large enough to give adequate fire protection. The statements of the Peoples Water Company as given for rate-fixing purposes indicate that their Richmond system has never been operated at a profit until the year 1912. Under these conditions it is very difficult for a privately owned system to finance extensions and improvements, which will keep pace with a rapidly spreading community such as Richmond. This difficulty has been reflected in the attitude which the Peoples Water Company has maintained toward ertensions of their distribution system. Their usual practice has been to make the consumer construct the desired extensions and turn them over to the water company, after which they would supply water at the usual rate, the extension becoming the property of the company and so used in fixing valuations for the rate fixing. Whether this policy is equitable is open to question, but its effect in retarding the growth of the community cannot be doubted. As part of the recent great activity in real estate and the high class improvements being put in many of the new tracts, distribution systems of small pipe have been installed by the tract owners prior to marketing their lots. This is a very commendable policy, but it is difficult to get the pipe of sufficient size to give proper fire protection. Under present conditions it is about the only practical means of securing important extensions of distribution systems in new territory.

Inadequacy of Present Sources of Supply.

At the present time all the water used in Richmond is obtained locally from underground sources. The draught on the underground waters within the district is from 3 to 4 million gallons per day. That this is probably in excess of the normal amount by which the underground gravels are annually replenished, is shown in Chapter No. V. The last two seasons 1911-1912, 1912-1913 have been dry seasons, so that the underground supply is now below the average. The last two seasons, however, are not necessarily the worst conditions and it is entirely possible that there will be a recurrence of conditions as bad as the present ones. That the draught is in excess of the normal supply is shown by the fact that the water table in many portions of the district has fallen as much as 30 feet in recent years. Mention has already been made of the fact that in 1907 the San Pablo No. 2 group of wells, typical of wells tapping the best underground flow, yielded under test 2 million gallons per day. The average daily yield of these wells is now only 600,000 gallons per day, an indicated decrease of nearly 70 per cent.

Mr. Arthur L. Adams at the time of this test estimated "As long as the underground waters of this cone held out, it would be safe to draw on the water-bearing strata to the extent of 2,000,000 gallons per day." For a number of years the actual draught has probably been twice this amount, occasioning a serious depletion of the underground storage. The other wells of the smaller water companies are in the narrow marginal plain between the base of the hill and the bay shore. The water-bearing gravels underneath this plain have no extensive source of supply, and hence their yield is necessarily limited, as shown in Chapter No. V.

It is evident that as a primary source of supply, the wells now in use are hardly dependable for a continuation of the present yield, much less for the increase most urgently needed at once. There is little justification for the water companies to make extensions to their distribution system without providing some additional source of supply.

The Peoples Water Company apparently appreciate the fact that the water-bearing gravels of the San Pablo cone are being pumped to excess, and are now going far up San Pablo Creek and boring a number of wells to augment the supply of San Pablo Station No. 1.

At the present time, they are pumping water back from Berkeley to Richmond. However, the total water supply on the east side of the bay as discussed in Appendix No. 4 is not sufficient to justify the continuous diversion of water to Richmond from the larger and more important communities to the south. With the rapidly increasing population of Oakland and Berkeley, all the water which the Peoples Water Company can supply from sources now in use will be urgently needed.

General plans were made in 1907 for extensive increase in the supply by development of the surface runoff, and construction actually started. This was suddenly stopped, however, and has not yet been resumed, presumably because of difficulties in financing the work. If, as shown, there is a lack of sufficient water to meet with certainty the requirements of the present consumers, then extensions are difficult, especially in territory which is for the immediate future relatively unproductive.

Unsatisfactory Quality of Water.

The quality of the water obtained from many of the wells is not satisfactory, being too hard for industrial use. The excessive amount of mineral matter and total hardness makes it undesirable for use in boilers and injurious and expensive for laundry purposes.

Typical analyses are shown in the following table:

Table No. 25—Analysis of Richmond Well Water With Parallel Figures for Sacramento River Sample.

ANALYSIS OF SAMPLES TAKEN NOV. 1, 1913.

Impurity.	Union Water Co., Fay Real Estate, Richmond.	Peoples Water Co. Richmond Wells.	Peoples Water Co. East of San Pablo Ave. Co. Line.	Sacramento River at Baker's Pt.
	Figures given are parts per million			
$SiO_2+Al_2O_3+Fe_2O_3$	21.8	21.4	19.4	19.2
Ca	45.6	150.2	84.0	16.0
Mg	19.0	52.8	33.4	7.8
Na	48.0	98.7	46.6	14.0
Cl	34.1	399.0	129.2	12.8
CO_3 equivalent to the HCO_3	136.9	129.0	127.2	46.6
SO_4	17.1	31.1	50.4	6.4
Total dissolved matter	322.5	882.2	490.2	122.8
HCO_3 (the way the carbonic acid exists)	278.4	262.3	258.7	94.7
Temporary hardness computed as $CaCO_3$	228.2	215.0	212.0	77.6
Total hardness computed as $CaCO_3$ from calcium	114.0	376.0	210.0	40.0
from magnesium	78.0	217.0	137.0	32.0
Total	192.0	593.0	347.0	72.0

As the Peoples Water Company Richmond Wells were high in chlorine an independent test was made November 10, 1913, resulting in 650 parts per million.

It will be noted that all of the wells tested are much higher both in chlorine content and in total hardness than the Sacramento River water. Because of the large expense caused by these constituents when the water is used in boilers and for other purposes, this is a very important consideration.

At the Pullman shops the water is softened by the use of the following formula:

"For each 100,000 gallons of fresh water used in boilers, the following ingredients:

135 pounds caustic soda
22½ lbs. Nalonea extract
23 pounds glucose"

The latter making the salt crystals forming on the boiler tubes easy to remove.

At the present time excessive pumpage in wells near the shore of the bay has lowered the water plane considerably below the level of tide water. In such cases there is danger of reversal of the normal underflow and of contamination by salt water. In a number of cases

the salinity is already so high that the water is quite brackish and unpleasant to the taste.

Analysis of samples recently obtained as tabulated above, shows as high as 660 parts per million of chlorine in water pumped from the Richmond wells of the Peoples Water Company. One hundred parts per million should be about the upper limit, although 50 parts is more desirable. Normally the Sacramento River water does not contain more than 10 parts.

In any thickly settled community the use of wells, especially shallow wells, is certain to become objectionable because of the danger of surface and sewage pollution. There is no evidence of this as yet, but it is certain to become apparent as the districts in the immediate vicinity of the wells are built up.

Distribution Systems.

The distribution systems, particularly of the smaller water companies, and to a lesser extent of the Peoples Water Company, are unsatisfactory, chiefly because of the inadequate fire protection afforded. In no case is there sufficient reservoir capacity to provide water for a general conflagration or to insure a supply in case of temporary failures of pipe lines or pumps. Additional reservoir capacity should be provided on the adjacent hills. In none of the smaller water companies is the pipe of sufficient size to justify the use of hydrants, and hence there is practically no fire protection. As generally understood, the same comment applies to most of the Peoples Water Company's distribution system, except that in the business district. In all of the smaller systems the pressures are entirely inadequate and the pipes are so small that in case of any considerable draught for fire use, nearly all the available head would be used in overcoming friction losses.

In a portion of the territory south of the Santa Fe Railroad there is insufficient water even for ordinary domestic purposes and the pipes are so small that the friction losses in transit are uneconomical.

Much of the distribution systems, particularly of the smaller companies, are incapable of sustaining the higher pressures desirable, were they to be incorporated into a first-class distribution system. Many of the pipes are either new or second-hand, and designed for only the small pressures to which they are now subjected. The presence of second-hand pipe in some of these systems is a particularly serious defect, as its life and strength is uncertain and its ability to stand shocks such as come from water hammer very doubtful. In these systems there is little pipe installed except ordinary commercial standard 2-inch and smaller, which is capable of sustaining under working conditions heads of over 200 feet.

The poorest service seems to be in the district containing the present populated summit of the Potrero Hills, on the west or Point Richmond side of the town, and the district south of the Santa Fe Railroad, between 1st and 16th Streets, on the east side of the town. Consumers complain that the supply is inadequate even for domestic consumption. It is said that there are places where, in order to obtain water for a bath, it is necessary to ask the neighbors in the block to stop sprinkling their lawns.

In these sections there is no pretense of adequate fire protection. As an instance of this, during the early part of 1912 the residence of Prof. Jahnke in the Potrero section of town on Crest Avenue near Washington was burned, with the complete destruction of valuable scientific instruments and data. The available supply of water was not sufficient to throw a hose stream to the fire from any point which could be occupied. Bystanders state that the stream spouted only 4 or 5 feet from the hose nozzle.

Rates.

In spite of the relatively poor service afforded, the meter rates charged are generally $1.50 per month minimum and 35 cents per thousand gallons. These are the same as charged by the Peoples Water Company in the balance of the Bay District, but they are materially higher than the normal for communities of this sort as shown in detail in the following chapter.

There is a general feeling that the water service is very poor in return for the amounts paid and that it is not only desirable to improve the quality and pressure of the water service, but, if possible, to reduce the average price, especially to the small consumers.

CHAPTER IV.

Requirements for a New Water Supply

GENERAL REQUIREMENTS.

The standards of modern public water supplies are being steadily raised as the communities grow in size and resources. Particularly is this true concerning the sanitary conditions surrounding the water supply.

The theory of the bacterial origin of contagious diseases is quite recent. Only within the last few years has the significance of water-borne bacteria been demonstrated. The extent to which the prevalence of diseases transmitted by bacteria in the drinking water can be controlled by improving the sanitary quality of the water supply is just beginning to be appreciated.

With the great increase in the size and luxury of American cities has come a demand that the water supply should satisfy higher aesthetic standards such as appearance, taste, temperature. The per capita consumption has also steadily increased, an effect which is natural with higher standards of living, more bath tubs, more water fixtures, more flowers and lawns.

Most American cities are constructed chiefly of wooden buildings so that the per capita fire loss is enormous, especially so in comparison with European cities. Chief reliance for fighting fires and preventing general conflagrations is now thrown upon the water supply, which is called upon to furnish at all times and with certainty in any part of the city, an ample supply of water at sufficient pressure for fire protection.

QUANTITY.

The quantity of water used in any given community depends upon many features, such as the growth, the population, habits of the people, the nature of the soil and climate, and the extent of the industrial consumption.

This has such a vital bearing on the selection and development of the water supply that it has been studied in detail in a special chapter, Chapter II, in which on page 44, Tables Nos. 16 and 17, is given the estimated present and predicted future per capita and total consumption.

QUALITY.

To be of acceptable quality, a modern public water supply must be pure and wholesome, judged both by health and aesthetic standards.

(*) "Pure and wholesome water" is not a substance of absolute quality. Strictly speaking, pure water does not exist in nature; all natural waters contain substances in solution or in suspension; and in proportion as these substances are present, and in proportion as they are objectionable in character, the water is impure. Definitions of pure and wholesome water, therefore, generally state what for-

eign substances shall not be present, or in what amounts they are permissible, instead of defining the positive qualities which the water shall possess.

"Unquestionably the term 'pure and wholesome water' as ordinarily used, relates to water intended to be used for drinking. Such a water must be free from from all poisonous substances, as the salts of lead; it must be free from bacteria or other organisms liable to cause disease, such as the bacilli of typhoid fever or dysentery; it must also be free from bacteria of fecal origin, such as B. coli. In other words, the water must be free from poisonous substances, from infection and even from contamination. (By this term is meant pollution with fecal matter. Contamination must be considered as potential infection.) Besides this, it must be practically clear, colorless, odorless, and reasonably free from objectionable chemical salts in solution and from microscopic organisms in suspension. Moreover, it must be well aerated. Color, turbidity, odor, dissolved salts, etc., may be permissible to a small degree without throwing the water outside of the definition of 'pure and wholesome water.' In these minor matters local standards govern up to a certain point, and it is in regard to them that differences in the judgment and experience of analyses lead to diverse classifications.

"When it comes to using water for other purposes than for drinking, other attributes have to be considered. Hardness makes a water troublesome to wash with and to use in boilers; iron makes trouble in the laundry; chlorine corrodes pipes and makes work for the plumbers; the presence of the carbonates and sulphates of lime and magnesia affects the papermaker, the brewer, the tanner, the dyer, the bleacher; soda causes a locomotive boiler to foam, and affects the use of water for irrigation. All of these constituents, and others which are not named, have to be taken into consideration in connection with a public water supply, which may be put to any of these uses."

(*) From "The Value of Pure Water," by Geo. C. Whipple.

Water-Borne Diseases.

The sanitary quality of a public water supply can now be judged more or less accurately by the prevalence of water-borne diseases in the community using it. The relationship between public water supply and public health is now clearly shown by the prevalence in communities using water supplies containing pathogenic organisms, of diseases produced by these organisms.

The most typical of these water-borne diseases is typhoid fever. This fact is now so generally understood that the typhoid fever death rate in a community is a convenient standard by which the sanitary quality of the water supply may be judged.

(*) "Typhoid fever is by no means the only disease transmitted by contaminated water. Dysentery and various other diarrheal diseases precede it or follow in its train, and in most instances these are probably due to the same general sources of contamination as those which caused the typhoid fever, although, of course, to different specific infections."

In water drawn from any surface supply or from wells in a polluted area, there is always constant danger from water-borne diseases. This danger increases with the density of population so that it is probable that there are few surface supplies of any sort which will not eventually be filtered, and where necessary, sterilized.

The protection afforded by properly designed and operated filters, especially if the water is also sterilized, is so efficient that any ordinary stream, even though subject to large amount of sewage pollution, will, if properly filtered furnish a safer supply than the best guarded and isolated surface supply, if untreated. The Bubbly Creek filter plant of the Chicago Stockyards treats water which is about half sewage.

(*) From Whipple's "Value of Pure Water."

After being filtered and sterilized the effluent is consistently of better quality than the Chicago city supply which is taken untreated from Lake Michigan.

Hardness.

The term "hardness" as applied to water refers to the salts of calcium and magnesium, particularly their carbonates and sulphates, but it is popularly applied as well to other substances, such as iron, sodium chloride, and even free acids or alkalis. It is common to estimate the monetary losses from the use of hard water by calculating the amount of soap necessary to soften it, in washing and laundry operations. The harder the water, the more soap will the community use. On the basis chiefly of additional soap consumption, Whipple estimates the financial loss from hardness in a public water supply at 10 cents per million gallons for each part per million. On this basis a difference of 100 parts per million in total hardness is worth $10.00 per million gallons.

There are other secondary objectionable features connected with the domestic use of hard water, such as unsatisfactory results from washing and bathing, additional water in laundry operations, encouragement of the use of strong soaps and washing compounds, which may injure certain fabrics. In almost every instance, where chemical manufacturing processes involve the use of water, hardness is objectionable. It renders more costly the operations of bleaching, dyeing, tanning, sugar refining, paper making, brewing, distilling, ice making, printing and many others, to an extent possible to estimate in dollars and cents. The effect of hard water in steam generating is still more serious. This is especially true in larger plants where the effort to obtain the maximum economy in steam production has resulted in the use or many auxiliary attachments to the modern boiler. Bad boiler water may cause corrosion, scale, foaming, overheating and leaks, resulting in lower efficiency, increased cost of attendance, operation and repairs, and shorter life for the boilers and increased danger of explosion.

Boiler scale is chiefly due to the precipitation from water, of carbonates and sulphates of calcium and magnesium. The resistance of sulphate scale to the passage of heat is 20 to 50 times as great as that of an equal thickness of wrought iron. It is sometimes stated that a boiler scale ⅛ inch thick will cause a loss of 20 per cent in the heat utilized from the fuel and ⅜ of an inch thick a loss of 50 per cent. The importance of this matter is generally recognized in large industrial concerns where hard waters are treated chemically before being used for making steam.

(*) "The point at which a water becomes objectionably hard has never been exactly defined. Standards of hardness vary in different parts of the country. The ordinary person washing his hands considers the water soft if the soap will quickly produce a suds without curdling. A hardness of 10 parts per million is practically unnoticeable and it requires a hardness of 20 to 30 parts per million to produce 'curdling.' Waters which have a hardness below 25 parts per million seldom cause much complaint, but when the hardness rises above 50, the water is well entitled to the appellation 'hard,' and above 100 it may be called very hard."

Aesthetic Considerations.

The qualities which relate to the general attractiveness of a water are those of taste, odor, color and turbidity. The actual or relative

(*) From Whipple's "The Value of Pure Water."

value of any of these is chiefly a matter of individual taste. Some persons are much more fastidious than others regarding the odor, color or turbidity of the water they drink. As these quantities increase in amount, the water becomes less attractive until the point is finally reached where the people refuse to drink it. The objections of representative water consumers may have much to do with the growth of any city. A monetary value can be attached to deficiency in this regard by noting, where a water supply is bad, the additional cost to the consumers for the use of filtered or spring water in preference to the public supply.

To be palatable, water should be delivered to the consumers at a fairly low temperature. If the water is too warm it can, of course, be cooled by mechanical processes or by the use of ice, but the cost of this is usually prohibitive for a public supply.

Effective Filtration.

Modern methods of water filtration have been thoroughly perfected in recent years. Almost any supply can be made thoroughly satisfactory from every standpoint, including aesthetic deficiencies. Filtration will remove the turbidity, color and nearly all the bacterial contamination. If the danger of sewage pollution is serious, the effluent from the filters can be easily sterilized with hypochlorite of lime. If the water is objectionably hard, it can be chemically softened.

For further information concerning the rapidly extending use of filtered water and the certainty of the results obtained see Appendix 7.

POSSIBILITY OF EXTENSION.

In choosing the source of supply for any rapidly growing community the practicability of future extensions must be carefully investigated.

As additional water is required, it is obviously economical to be able to enlarge the sources then in use by the construction of additional units of the same character. Public health is best conserved by supplying all parts of a community with water of the same composition. It is hence unfortunate when enlargements are made to be compelled to seek new sources of supply. It is accordingly desirable to select a source of supply which will certainly meet the maximum future requirements of the community.

When a new water supply is developed, it is usual to provide capacity in excess of immediate needs, in order that the principal parts of the construction work may not require enlargements until the approach of the end of their life, necessitating replacemnt.

RELIABILITY.

As water is an absolute necessity, it follows that the selection of the source of supply and the design of the water works should be such as to absolutely insure a sufficient supply at all times. This requires a study of the minimum, rather than the average production of the source considered. If water is taken from a flowing stream, one must be selected in which the extreme dry weather flow is ample under all

conditions. If the supply is to be obtained from stored surface water, sufficient storage must be provided to bridge over the inequalities of the season's runoff and to provide a uniform and ample supply during the most critical series of dry years. The same conditions apply to a well supply, where water is drawn from an underground stream or reservoir in which it is naturally stored in a similar manner.

Where the water supply is brought to a community from a distance, the design of the conduit, especially, to guard against interruption of the service, is of vital importance. Unforeseen accidents, such as earth slides, washouts or floods can easily cause temporary interruptions of service. Where it is economically practical, the most critical points in the conduit are sometimes duplicated, but the additional protection thus afforded is not great since any accidents sufficient to cause failure in one line will usually affect similarly other parallel lines. The safest provision, and the one customarily made is to require a considerable amount of water to be stored close to the point of consumption and frequently at other convenient points along the line of the conduits. Where dependence is placed upon pumping machinery or other complicated mechanical features, it is usual to have several units and if the pumping plants are isolated, to provide alternate sources of power. Emergency intakes, reserve equipment, and temporary storage should also be provided wherever practical.

Advantage of Gravity Supply.

A distribution system supplied by gravity is much more dependable than one in which sole reliance is placed upon the continuous operation of pumps. This is particularly true from the standpoint of fire protection, where even a few minutes' interruption may be fatal.

For storing water, dams of earth or masonry are usually required, and if properly protected against the possibility of overflow, and properly designed, they are one of the most permanent and desirable forms of engineering construction.

PRESSURE AND FIRE PROTECTION.

Desirable Pressures for Domestic Use.

The pressure at which water should be distributed to domestic consumers is ordinarily dependent upon the requirements for fire protection. For domestic service alone, comparatively low pressures ranging from 20 pounds to 50 or 60 pounds per square inch are preferable. High pressures cause a greater strain upon plumbing fixtures, and in many water supplies, an additional cost for pumping. If pressures are much less than 20 pounds per square inch, extra large fixtures are necessary to give a free flow of water. Ordinary plumbing fixtures can safely stand pressures from 100 to 150 pounds per square inch. If the pressure in the main exceeds this, pressure reducers should be installed. The tendency is toward the use of higher pressures. One of the reasons is the increasing height of buildings in American cities, frequently rendering it necessary to install pumps to lift the water to roof tanks. It is always desirable also to be able to extend a distribution system on to higher land as a city grows. Where there is much difference of ele-

vation in different portions of a city, separate pressure zones are necessary.

Pressures and Quantities for Fire Protection.

The total amount of water necessary for fire extinction is a very inconsiderable portion of the total consumption. For limited periods however, the maximum rate at which water must be delivered for fire protection may far exceed the requirements for domestic consumption. The maximum amount of water required for any particular fire or series of fires within a limited district has been very carefully and widely investigated. It is a critical feature of the design of the distribution system, and of many other parts of a general water supply system. The requirements for this purpose fix the size of all pipes of a distribution system, except the largest mains. They fix the spacing of hydrants, and frequently the capacity of reservoirs or pumping plants. Estimates are usually based upon the assumed number of fire streams of a given capacity and pressure which it should be possible to concentrate in a limited area for the extinction of a fire, and the protection of adjacent property.

The following data is taken from a report on a high pressure fire protection system for the city of Berkeley by J. J. Jessup, City Engineer, May 12, 1913.

"The standard fire stream is that discharged through an 1⅛-inch nozzle, with a nozzle pressure of 45 pounds per square inch. This gives a discharge of 250 gallons per minute.

"Obviously, the number of fire streams to be provided for, bears some relation to the population of the community served. The number of streams that have been used in the maximum fires of cities of various sizes has been observed by Fanning, Freeman, Kuichling and others. On the basis of these obseravtions, for cities of 50,000 to 100,000 the following number of streams has been determined as necessary:

"Fanning—14 to 18.
"Freeman—12 to 15 (Min. req.), 18 to 22 (Max. req.).
"Kuichling—18 to 28.

"The suburban character of Berkeley, with its proportionately large residential section will continually tend to lower the fire hazard below that of a normal city of the same population and materially lessen the maximum requirements for fire protection.

"The following is a record of some of the actual amounts used in extinguishing various fires:

"Boston, Mass., Harcomb Bldg., 118,000 gals. per hour.

"Brooklyn, N. Y., 8 one-story, 12 two-story, 2 three-story, lumber yard—7 hours duration, 105,000 gals. used.

"Philadelphia, Jan. 9, 1906, 1 hr. 54 min. duration, 136,800 gals. used; Jan. 11, 1906, 1 hr. duration, 294,000 gals. used; Mar. 29, 1907, 1 hr. 48 min. duration, 282,000 gals. used.

"St. Louis, Mo., Collier Lead Wks., 3,375 gals. per min.

"Fall River, Mass., Border City Mill, 2,400 gal. per min.

"Providence, R. I., Aldrich House, 4,400 gal. per min.

"Lynn, Mass., general conflagration, 6,700 gal. per min.

"Based on observations on the length of time the maximum fire draught has been maintained, Freeman concludes that a provision for six hours of maximum draught is ample. On this assumption, provision must be made in Berkeley for a consumption of 1,080,000 gallons in a single fire, or concurrence of fires, which draught should be met without weakening a safe reserve.

"As has been stated, the requisite nozzle pressure for a standard fire stream is 45 pounds per square inch. Mr. Joseph R. Freeman has conducted a series of tests on the hydraulics of fire streams in which the losses of pressure in fire hose

and nozzles has been carefully determined. Using 2½-inch cotton rubber-lined hose with an 1⅛-inch nozzle, a friction loss of 14 pounds pressure per 100 feet length of hose occurs, so that for 500 feet hose length (a common assumption) the hydrant pressure required for a standard stream with valve open is 120 pounds per square inch. This pressure in addition to the friction loss in hydrants, distribution pipes and supply lines when the full supply is being delivered, represents the static pressure that must be maintained on the hydrants to give the system the designed capacity.

"The full pressure necessary to supply the maximum flow above outlined is not generally maintained on any fire protection system, owing to the continual strain in hydrant valves and the entire distribution system, with the resulting loss of water by leakage at the joints. As an example, in Oakland, where the district served is practically level, a static pressure of 50 pounds per square inch is maintained in the pipe lines, which is increased whenever the system is thrown into service, by starting the pumps. The same effect is produced in San Francisco by throwing into service reservoirs of higher elevation than those used to produce the static head."

In a city such as Richmond, which during the life of the distribution system will have a population of 100,000 or more, it would be reasonable to provide for 10 to 20 standard fire streams with a total capacity of 2,500 to 5,000 gallons per minute for the business and industrial districts, and for the suburban and residence districts, about half of this amount.

Insurance Rates.

The rates fixed for fire insurance are dependent to a considerable degree upon the fire protection afforded by the water system. The following is a statement of the fire underwriters' rules covering increase of rates for insurance where the protection afforded is less than desired. (*)

"*Standard City Protection—*

"Gravity system, with sufficient head at all hours to give pressure at hydrant of not less than 80 pounds (which will give stream 1¼-inch nozzle and 100 feet hose), 80 to 100 feet high.

"The main supply pipe to be in duplicate or intermediate reservoirs provided. Reservoir or source of supply to have capacity for at least 5 days' supply for domestic and fire purposes.

"Water mains and hydrants to be in accordance with the specifications of National Fire Protection Association; not less than 6 inches in dwelling sections, and not less than 8 inches (as a minimum) in mercantile section. Hydrants to be not more than 150 feet apart in mercantile district and 300 feet in dwelling district.

"Full Paid Department—Ten men to each steamer or 4 men to each hose cart when gravity system or direct pressure is relied upon. Two steamers (with hose carts carrying at least 1,000 feet of hose for each steamer), to each square mile of compact district, or one to each 10,000 population (not less than two in any case). When gravity system or direct pressure is relied upon, two hose carts and 1,000 feet of hose are considered the equivalent of one steamer.

"One hook and ladder truck to every four steamers or four hose carts.

"One chemical engine or two combination chemical engines and hose wagons for each 50,000 population or fraction thereof.

"In sea and river ports fire-boats properly equipped and manned as required.

"Approved fire alarm telegraph.

"Efficient police department.

"Streets in mercantile district macadamized, paved or of other hard material, 60 per cent of which are not less than 70 feet wide.

"Approved city ordinances, well enforced.

(*) From standard regulations Pacific Fire Underwriters Assn., 1913.

"No outlying exposure, or conflagration hazard.
"Climatic conditions, good.

"*Charges for Deficiencies in Department and Water Supply*(*)—

"1. Unprotected towns—Towns without water supply for fire purposes, other than private cisterns and wells, and without fire alarm telegraph, an organized police system, fire department, fire marshal, or building ordinances, charge 35c.

"*Water Works.*

"2. Gravity System—If not standard pressure, being simply sufficient to keep mains full for supply engines, 2c.
"NOTE—This deficiency will necessitate charge No. 15, if no steamers to supply needed pressure.
"3. Reservoir (gravity system)—If reservoir for gravity system is not of standard capacity (5 days' supply for domestic and fire purposes) charge according to supply, 3 to 7c.
"4. Direct Pressure System—If not gravity, standard pressure, but instead a direct pressure system, duplicate pumping machinery operated by water or steam power plant, in a brick or stone unexposed building, charge 3c.
"5. Direct Pressure System—If as above, but pumping machinery not in duplicate, charge 5c.
"6. Direct Pressure System—If pumping machinery in duplicate but plant in detached, frame pump house, charge, instead of No. 4, 4c.
"7. Direct Pressure System—If as above, but pumping machinery not in duplicate, charge 7c.
"8. Direct Pressure Standpipe—If direct pressure but without standpipe or reservoir with capacity for 10 hours' supply (unless pumping machinery is in duplicate, in which case, add 2c) charge, in addition to 4, 5, 6 or 7, 5c.
"9. Pumping Station Exposed—If endangered by exposure or occupied for another purpose, make an additional charge, depending on the exposure or hazard, 5 to 10c.
"10. Supply Mains—If not duplicate supply main from reservoir or pump house, unless intermediate reservoir connects independently with city system, charge 2c.
"11. Distributing Mains—If water mains in mercantile district be less than 8 inches, but 6 inches or more, charge 3c.
"12. Distributing Mains—If water mains in mercantile district be less than 6 inches, charge, instead of No. 11, 5c.
"NOTE—Charges 11 and 12 must be made when there are not enough mains of a size exceeding the minimum to meet the requirements of good service.
"13. Supply Not Under Pressure—If the only supply is from cisterns and wells or natural streams, canals, near enough to be available with engine suction, charge, instead of 2 to 12, 10c.
"14. Hydrants—Insufficient number, or too far apart, charge 1 to 3c."

Comparing with the present system the above requirements, it will be seen that of the improvements which may effect a considerable saving about one-half would be due to gravity distribution supplying proper pressures, and about one-third due to a closer hydrant spacing.

Fire Department.

A system of fire protection in accordance with the above requirements of the insurance underwriters for their basic rate practically eliminates the necessity for the use of pumping engines, and, therefore, materially reduces the first cost, and the operating cost of fire departments. The use of any distribution system with sufficient capacity and pressure to permit the use of fire fighting apparatus which can be directly connected with the hydrants, effects a big saving.

(*) Figures shown are additional annual charge in cents for each $100 insurance.

Insurance Rates and Fire Hazard.

The results of Table No. 1 indicate the number and direction of wind storms severe enough to greatly increase the fire hazard and the probability of a small fire developing into a general conflagration. It will be seen that the prevailing winds blow toward the east and northeast. There is a considerable portion of the time during which general conflagrations starting in the southwest portion of the city, that is near the future harbor and industrial district, might become destructive, because of wind making it extremely difficult to fight fire on the leeward side. Danger of a general conflagration at the present time is not very acute, because improvements are too scattered, but this condition will not long continue. The railroad embankments cutting the city into several sections now furnish excellent fire barriers.

Richmond has not so far been visited by any general conflagration, and hence the insurance rates are not now exorbitant. They are, however, about 7 cents per $100.00 more than the lowest rates given to cities with the best protection. The policy of fire insurance companies is to place the fire loss as nearly as possible on the community where the damage is sustained, underwriting the hazard so as to spread this loss over a term of years. While now enjoying good insurance rates, though with little fire protection, Richmond would have to make up by increased premiums any loss caused by a general conflagration. The percentage increase in fire insurance rates due to any increase in fire loss is always marked. Thus in Pittsburg in 1902, the rate was increased 20 cents per 100. In San Francisco after the fire of 1906, the rates were increased in some districts more than 200 per cent.

With first-class fire protection it ought to be possible to reduce the insurance rates now in effect in Richmond. Without such fire protection the community can hardly hope to permanently escape a disastrous conflagration, which would have to be paid for in greatly increased premiums. The expenditure justifiable for reduced fire hazard is determined by many considerations other than monetary saving in insurance premiums. There is a large economic loss to a community from fires, which is not covered by insurance, such as interruption and disorganization of business, loss of income from idle property, loss of employment, depreciation of property in the vicinity of a disastrous fire loss on uninsured property and stock, and occasional loss of life or injury to persons.

Insurance in Richmond.

For purpose of arriving at a very general estimate of the value of reducing insurance rates or preventing them from being raised, it may be assumed that the value of improvements is twice their assessed value, and that the amount of insurance carried is half the value of improvements or equal to their assessed value.

The following table has been prepared based on similar assumptions in order to predict the total amount possible to save in insurance premiums for a reduction of one cent per $100.00 in insurance rates, and the permanent investment justifiable at 5 per cent to reduce the premiums.

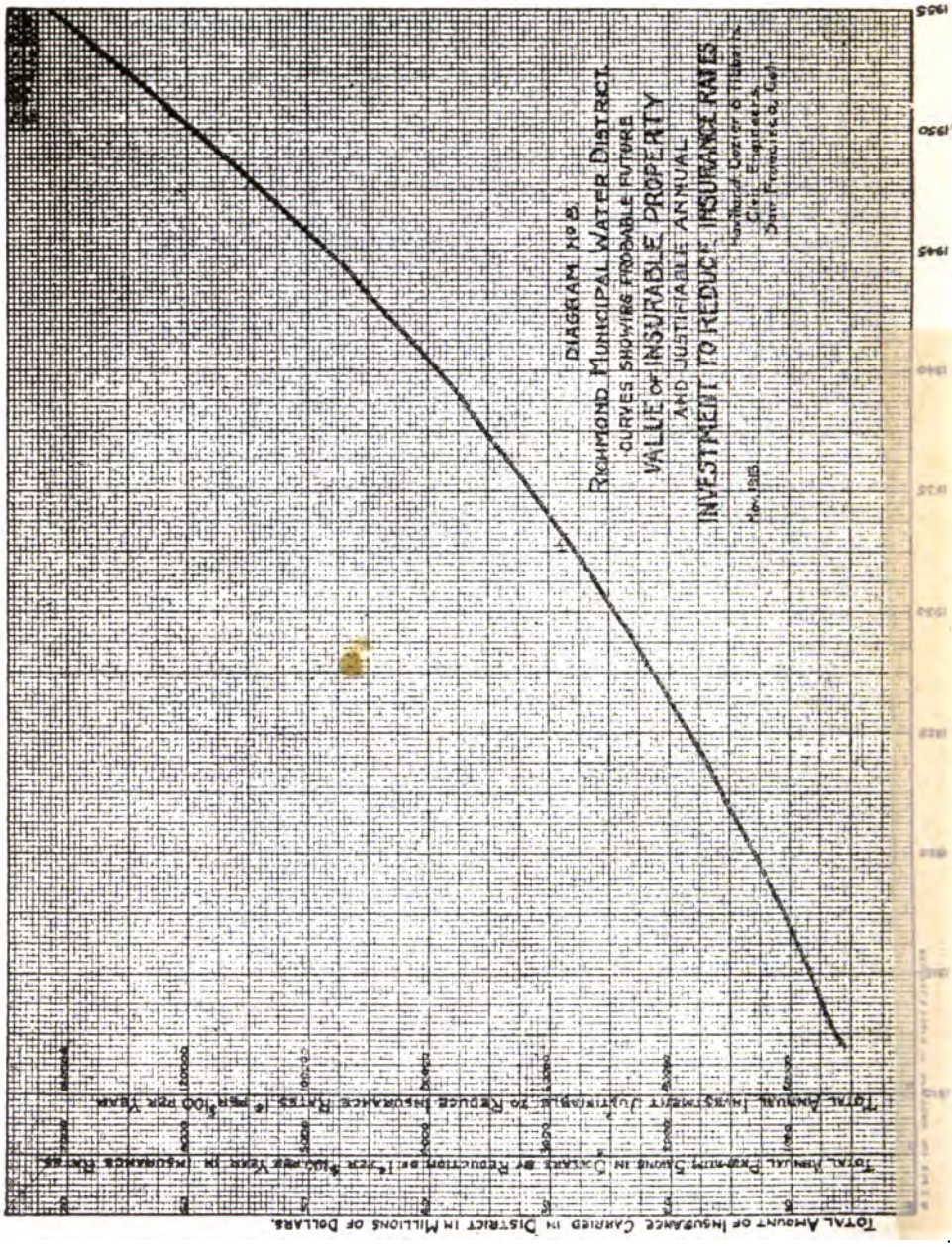


DIAGRAM No 8.
RICHMOND MUNICIPAL WATER DISTRICT
CURVES SHOWING PROBABLE FUTURE
VALUE OF INSURABLE PROPERTY
AND JUSTIFIABLE ANNUAL
INVESTMENT TO REDUCE INSURANCE RATES
Nov. 1913
1905
1950
1965
TOTAL AMOUNT OF INSURANCE CARRIED IN DISTRICT IN MILLIONS OF DOLLARS.
TOTAL ANNUAL EXPENDITURE DURING 5 YEARS BY REDUCTION BY 1/2 PER CENT PER $100 PER YEAR IN INSURANCE RATES
TOTAL ANNUAL INVESTMENT JUSTIFIABLE TO REDUCE INSURANCE RATES 1/2 PER $100 PER YEAR

Table No. 26—Expenditures Justifiable to Reduce Insurance Rates in Richmond Water District.

Year.	Total Valuation.	Per Cent Factor.	Assessed Valuation of Improvements and Pers. Prop.	Annual Ins. Prem. at rate of 1c per $100.	Permanent Annual Investment Justifiable to save 1c in Insurance Rate.
1912....	$ 15,927,995	34.4	$ 5,483,250	$ 548	$ 10,960
1913....	19,405,305	35.0	6,790,000	679	13,580
1914....	21,060,000	35.5	7,475,000	748	14,960
1915....	22,800,000	36.0	8,200,000	820	16,400
1920....	34,400,000	37.5	12,900,000	1,290	25,800
1925....	46,750,000	39.0	18,220,000	1,822	36,440
1930....	59,900,000	40.5	24,250,000	2,425	48,500
1935....	74,800,000	42.0	31,400,000	3,140	62,800
1940....	89,900,000	43.5	39,100,000	3,910	78,200
1945....	107,400,000	45.0	48,350,000	4,835	96,700
1950....	127,800,000	46.5	59,450,000	5,945	118,900
1955....	148,700,000	48.0	71,450,000	7,145	142,900

NOTE—Total valuation excludes operative property.

Assessed valuation of improvements and personal property includes operative property and is assumed equal to insurable value.

The assessed valuation of improvements and personal property in Richmond Municipal Water District in 1912 was compiled from the official records in the County Assessor's and Auditor's offices.

The percentage factor for year 1955, when Richmond will probably be a city of a size comparable to Oakland in 1906, was obtained by comparison and average of similar figures for San Francisco and Oakland as follows:

Average ratio of assessed valuation of improvements and personal property to total assessed valuation (exclusive of operative property) in San Francisco for past 12 years = ... 48.9%
Corresponding ratio for Oakland for past 8 years = ... 46.8%

Average = ... 47.9%

Per cent factors for years between 1912 and 1955 were interpolated.

WATER RATES.

Water Rates Now Prevalent in Richmond.

The Peoples Water Company now charge in Richmond a minimum rate of $1.50 per month per service, and 35 cents per 1,000 gallons for small consumers, and 30 cents per 1,000 gallons for large consumers. The rates charged by the smaller companies are as follows:

Union Water Company, $1.50 per service and 32 to 25c per 1,000 gallons.
Fred H. Meyers, $1.50 per service.
McEwen Bros., $1.50 and $1.25 per service.
Herbert F. Brown, $1.50 per service.

Water Rates in Adjoining Communities.

The water rates given above for the portion of Richmond supplied by the Peoples Water Company prevail also in Oakland, Berkeley and other adjoining cities on the east side of San Francisco Bay.

As a guide to determining the normal or desirable rate, the following tables have been compiled showing the rates in 93 different cities and communities in California.

Table No. 27—Sliding Scale of Water Rates in Some California Municipalities, 1913.

Town.	Min. Rate.	For (Gals.)	Meter Rate Per 1000 Gallons 0-5M	5-10M	10-20M	20-50M	Over 50M
Dixon			.35	.35	.25	.07½	.07½
Lindsay			.30	.30	.20	.20	.20
Long Beach			.13	.13	.12½	.12½	.12½
Monterey	1.25	3600	.36				
Pomona	1.00	4500	(4500-18700) .133				
Pasadena	1.00	3750	(Over 3750) .10½				
Petaluma			.40	(5-15M) .30	(15-30M) .25	(Over 30M) .20	
Rio Vista	1.75	3000	(3-6M) .50	(6-15M) .40	(15-30M) .35	(Over 30M) .30	
Santa Maria	1.25	5000		.20	(10-30M) .15	(Over 30M) .12½	
Suisun			.50	(5-15M) .40	(15-30M) .35	(30-50M) .30	.25

Table No. 28.—Minimum Water Rates, California Municipalities, 1913.

Location	Min. Rate	For (Gals.)	Meter Rate Per M Gallons	Supplied by.
Anaheim	$1.00	5,984	$ .16.7	Municipality.
Azusa	.75	11,220	.06.7	Municipality.
Claremont	1.25	3,740	.33.4	Citizens Light & Power Co.
Glendora	2.20	7,480	.29.4	Glendora Water Co.
Los Angeles	.75	7,480	.10.0	L. A. Water Department.
Orange City	1.00	4,488	.22.2	Municipality.
Pasadena	1.00	7,480	.13.4	N. Pasadena Land & Water Co.
San Jacinto	1.00	2,244	.44.5	San Jacinto Water Co.
Tulare	....	....	.20.0	Tulare City Water Co.
Alameda	....	....	.30.0	
Alhambra	....	....	.17.7	
Antioch	....	....	.07.0	
Arcata	....	....	.35	
Bakersfield	....	....	.15	
Belvedere	....	....	.66	
Benicia	....	....	.75	
Berkeley	....	....	.35	
Chino	....	....	.35	
Coalinga	....	....	.47	
Colusa	....	....	.50	
Compton	....	....	.15	
Corona	....	....	.21	
Elsinore	....	....	.16⅔	
Emeryville	....	....	.20	
Eureka	....	....	.45	
Fairfield	....	....	.20 to 45	
Ferndale	....	....	.20	
Fresno	....	....	.25	
Glendale	....	....	.25	
Gridley	....	....	.10	
Healdsburg	....	....	.10⅔	
Hemet	....	....	1.00	
Hermosa Beach	....	....	.25	

Table No. 28 (continued).

Location	Meter Rates Per M Gals.
Hollister	.50
Huntington Park	.10
Imperial	.26⅔
Livermore	.20
Lodi	.15
Lordsburg	.31¼
Los Banos	.25
Los Gatos	.15
Martinez	.50
Monrovia	.10
Mountain View	.15
Napa	.40
National City	.25
Newport Beach	.40
Ontario	.13⅓
Oroville	.20
Pacific Grove	.35
Palo Alto	.20
Piedmont	.35
Pittsburg	.25
Placerville	.20
Pleasanton	.10
Point Arena	.22⅙
Red Bluff	.25
Redlands	.35
Redondo Beach	.17½
Redwood City	.30
Riverside	.40
Ross	.50
San Bernardino	.08 to .13⅓
San Buenaventura	.10 to .75
San Diego	.10
San Jose	.25
San Francisco	.13 to .30
Santa Ana	.10⅓
Santa Barbara	.20
Santa Clara	.20
Santa Cruz	.10
Santa Monica	.20
Santa Paula	.07
Sausalito	.50
Sebastopol	.20
Selma	.05½
Sonoma	.10
Stockton	.25
Vacaville	.50
Vallejo	.20
Visalia	.25
Whittier	.04
Yreka	.20

Desirable Water Rates.

A study of the above tables shows that of 93 communities listed, 68 or 73 per cent have water rates lower than those now existing in Richmond. It is, of course, desirable to have the retail rate as low as possible and to encourage a plentiful use of water. Since there are no unusual problems connected with the development of the Richmond water supply, it would seem that the present rates are too high. The quality of the water, especially its sanitary value, must not be sacrificed for economical reasons. In order, however, to at once monopolize the market in the Richmond Municipal Water District, it is greatly desirable not only to be able to furnish a better supply of softer water than that now used and to distribute it under much better pressure, but if possible to fix retail rates appreciably below those now existing.

PUBLIC OWNERSHIP.

Water is a unique and indispensable commodity. It is in the nature of things a monopoly and it is desirable in every community to have but one source of supply. The abundance and quality of the water supplied to any city should not be limited.

The present system of attempted public regulation through the city council produces unsatisfactory results in most California cities, and causes extensive litigation and uncertainty. It has resulted in the creation of an awkward and impractical method of fixing water rates. There is no satisfactory method of forcing the water companies to provide proper fire protection or to remedy defects in the source of supply. Public ownership has quite generally improved

conditions and there are practically no instances where once undertaken it has been abandoned. The quality of water and the amount of fire protection are greatly improved and the rates reduced. The credit of a large municipality is always better than that of a private individual, so that money for water works construction can be obtained at more favorable rates. In publicly owned systems there is no object in attempting to operate at a profit, so that water rates are generally materially reduced. Much more satisfactory co-operation can also be obtained with other departments of a municipality, such as the fire, health and park departments.

The advantages of public ownership have been abundantly demonstrated. The City Club of Berkeley, in a report on water supply, dated May 15, 1913, sent a questionair to all cities in the United States having a population of 50,000 and over and to all on the Pacific Coast having 2,000 and over. Seventy-five per cent of the cities written to were heard from, with the following results:

"Slightly more than three out of four of these cities own their own supplies. Their ownership is not experimental, but extends over periods varying from five to seventy-seven years. Detroit has owned its water supply since 1836; Cincinnati since 1839; Trenton, New Jersey, since 1857; Sacramento, Cal., has been operating its own water supply since 1859; Houston, Texas, purchased the plant of the private company in 1906. Jacksonville, Florida, built its own plant in 1880, etc. No. instance mentioned where public ownership once undertaken has been abandoned.

"Public ownership is not affirmed to be without its problems but the prevailing sentiment is emphatically that this plan is serving the public interest best. The amount of objectionable political activity in the water department is negligible. Only four cities mention politics as entering at all and in each case the influence has been slight. Cleveland, Ohio, ventures that there is more politics in private than in public ownership. Camden, N. J., says: Politics is 'Good for the organization.'

"In nearly all instances where public ownership has followed private ownership the quality of the water and the excellence of the service have been improved and the rates reduced. In some instances, the rates have been cut in half and in others after a material reduction of rates there has been a considerable excess of receipts over expenses and this income has been applied to other needs of the city.

"The public should profit by the ownership of its water supply through the elimination of such outlays as 'Directors' and 'inactive officials'' salaries, legal fees and litigation of which the public must now pay not only its own, but likewise that of the Water Company, lobby expenses, stock gambling, interest on watered stock, plant duplication by competing concerns that are later combined and the combined cost made the basis of computing water charges, the elimination of interest on unearned increment, the ability of the community to finance improvements of a far-reaching character and the securing by the community of a lower rate of interest than that at which private companies can borrow, the readier response to general public demand, securing the benefit to the community of the unearned increment on water, real estate, better care of watersheds, opportunity to co-operate with other departments such as health and fire departments, the establishment of greater public interest in water property, and greater vigilance on the part of householders to curtail not only their own tendency to waste and destroy, but also that of their neighbors."

Other Water Districts.

Another water district has been formed in Marin County and tentative plans made for construction work. The east bay cities of Alameda County are also contemplating the formation of a large water district.

Advisability of Prompt Action.

It is very desirable that immediate action should be taken in Richmond. The present condition is greatly hampering the growth of the city. There is grave danger of a serious conflagration with no adequate means of checking it. The present sources of supply cannot be enlarged and the draft on them probably cannot even be maintained at its present rate. The necessary works will take considerable time to construct, so that if started immediately, by the time rights of way are obtained, construction completed, and water actually delivered in Richmond, it will be very ungently needed.

CHAPTER V.

Underground Water Supply of District

FORMATION.

There is little accurate data regarding the formation in the underground water-producing section of the Richmond Water District. Some investigations were made by Professor Lawson, of the University of California, regarding the geology of the region with a view of getting an idea of the amount of water possible to develop from the San Pablo cone. The logs of all the wells collected show that there are no main well defined water-bearing strata. Water is found at various depths, evidently in isolated water-bearing strata or pockets. As far as known, no conclusions were reached regarding the amount of water available. The general formation is quite simple and evident. Much can be inferred from the study of surface conditions. At the base of the hills there has been built up a narrow marginal plain, formed of material washed down from the adjacent hills. Opposite the larger creeks there are larger alluvial fans or cones.

SOURCES OF UNDERFLOW.

Beneath the level lands in the district there are irregular strata or pockets of water-bearing sand and gravel. The water found in these strata evidently originates from rainfall and runoff on the adjacent watersheds and surface soil immediately above. The runoff from the larger mountain watersheds is concentrated in the creeks, and must reach the water-bearing gravel by seepage from the beds of the creeks in the comparatively limited area between the foot of the hills and the shore line. This condition is quite normal and very common.

Limitations of Underflow.

It is possible to fix a maximum limit of the amount of water which can probably be developed under such conditions. All such water originates in the known rainfall on tributary watersheds, and only a small portion of this can reach the water-bearing gravels and appear as underflow. Of the total amount of water thus reaching the gravels, only a small portion can be economically recovered by means of wells or underground galleries.

There is probably a slow but definite movement of the underflow toward the bay. It is impossible to develop a uniform yield over a number of years which is greater than a certain definite portion of this underflow. When wells are first bored, however, a supply can be obtained for a limited period much in excess of the normal, by drawing on the water stored in the gravels as from an underground reservoir rather than an underground stream. The effect of any withdrawals in excess of the amount which can normally be obtained from the underflow is to deplete the gravel storage and lower the

water plane. This result appears to have already been accomplished over much of the water-bearing strata of the district.

Where excess pumpage lowers the water plane permanently below the level of the adjacent water in the bay, a reversal of the normal direction of the underflow is certain to take place, resulting in contamination of the well supply by salt water. Reference has already been made to the fact that the yield from San Pablo wells No. 2 judging by tests made by the late Arthur L. Adams in 1907, has decreased as much as 70 per cent as the water plane has been gradually lowered. Also that Mr. Adams in 1907 estimated that the original yield of 2,000,000 gallons per day could be maintained only as long as the underground water already stored, held out. It seems evident that the underground sources in Richmond are already being drawn on to an extent in excess of their normal capacity. This has resulted in some cases in a marked deterioration of the quality of the water, and it is highly improbable that the present production of water from these sources can be maintained, and still more improbable that it can be increased. Inasmuch as the most productive water-bearing areas are fed by San Pablo and Wild Cat Creeks, it would appear that if any project for storing the runoff from these creeks in reservoirs in the hills is carried out, then the yield from these underground sources having its supply cut off, will gradually diminish. There is a very considerable portion, however, of the watersheds of San Pablo and Wild Cat Creeks, below dam sites so that the effect of the proposed dams might not be as great as anticipated.

PRESENT WELL SUPPLY.

A description of the location, construction and production of the more important wells now in use in Richmond is contained in detail in Chapter III.

At the present time in the district there are in the neighborhood of 320 wells ranging in depth from 20 feet to about 500 feet. Most of these are producing wells, and a few of them are artesian in the sense that they will overflow gently. Those wells in the marginal plain in what might be termed the "Pullman District", in the neighborhood of Cerrito Hill, have the water table very close to the ground, and if not drawn upon, will overflow gently. These wells are usually driven to a depth of about 100 feet. In the sections lying northeasterly from Cerrito Hill, or in the region east of Wall Street, and from Cutting Boulevard north to Grand View Terrace, the wells are driven from 100 to 140 feet in depth and the water usually stands 16 to 20 feet below the surface of the ground.

In the San Pablo and Wild Cat cones, the wells of the West San Pablo Land & Water Company and the Peoples Water Company pumping stations, San Pablo No. 1 and No. 2, are from 170 to 500 feet in depth, and are pumped against quite heavily. This excess pumpage, which is undoubtedly greater than the normal underflow, has caused a gradual lowering of the water plane throughout these cones. The surface of the ground is but 10 to 50 feet above mean tide level, averaging not over 25 feet. There is accordingly a very limited storage above tide level in the underground sources. It is the universal

experience with wells near bodies of salt water, that the level of the ground water cannot be pumped below sea level for any extended period of time without becoming salty and unfit for domestic use or steam boilers. Accordingly, if the quality of the water is conserved, use should not be made of underground storage below sea level.

Quality.

The quality of the water obtained from these underground sources is not generally unsatisfactory until excessive pumpage has resulted in salt water contamination. Analysis of typical samples was shown by Table No. 25 of Chapter III. The principal criticism is with regard to the total hardness, which as is usual from water derived from ground-water sources is undesirable for industrial use.

A number of samples were taken in September and October, 1913, for determination of chlorine content with the result shown in the following table:

Table No. 29—Chlorine Content of Well Waters.

Water Company	Location of Wells	Depth	Chlorine Content (Parts per Million)
Peoples Water Co.	Richmond Wells		660.0
Peoples Water Co.	San Pablo No. 1, Composite Line "A"		61.2
Peoples Water Co.	Well "B" (1 well with strong flow)		39.6
Peoples Water Co.	San Pablo No. 2, Single Well No. 5		41.6
Peoples Water Co.	Single Well ———		55.4
Peoples Water Co.	Composite of wells 6-8-10		47.2
Standard Oil Co.'s Wells.	Well No. 2	230 feet	36.8
	Well No. 12	290 feet	44.2
	Well No. 16	397 feet	38.6
Southern Pacific Co. Well		300 W	33.2
Santa Fe Co.'s Well			45.0
Hercules Powder Co			34.2
Peoples Water Co.	From tap at Curry Bottling Works		516
Curry Bottling Works.	Private Well		82
Peoples Water Co.	Berkeley—Service tap in North Berkeley		86
	(From Table No. 25, Chapter III—Tests Nov. 1, 1913.)		
Union Water Co.	Tap near Fay Realty Co. office		34.1
Peoples Water Co.	Santa Fe Wells		399
Peoples Water Co.	Tap east of San Pablo at County Line		129.2
Sacramento River at Toland's Landing			12.8

Exclusive of the group known as the Richmond Wells, the average of the above tests is 43.3 parts per million of chlorine. The normal chlorine content of the water in the Sacramento River at Toland's Landing was found by a series of tests on September 26th and 27th to be about 16.4 parts per million. It is difficult to set an absolute standard for chlorine content in a public water supply, but it may be stated that when the amount exceeds 85 to 100 parts per million it is near the permissible limit. Water with 500 to 600 parts per million has a distinctly brackish or salty taste, and when used in steam boilers causes considerable annoyance and expense. The high chlorine content of the Richmond wells is quite abnormal, and indicates probable contamination from sea water.

The level ground in the vicinity of the more important wells should eventually be utilized for subdivision and industrial purposes. When the areas immediately adjacent to the wells are thickly settled, it will no longer be possible to guard these wells from surface pollution. As the water would still be economically available, however, for local industrial use, this should be its final disposition.

THEORETICAL ESTIMATE OF UNDERGROUND YIELD.

Results of Experience Elsewhere.

It is possible by a series of assumptions based upon the rainfall and area tributary to ground water sources, to estimate the maximum possible from such sources. It is reasonable to assume that all of the water recovered from the gravel beds is supplied by that portion of the rainfall which runs off of the watershed, or from the stored waters resulting from runoff of previous seasons. The yield depends upon the rainfall, percolation, evaporation and general character of the watershed, as well as on the nature and location of the wells, galleries or other means of recovering the underground flow. Fairly accurate estimates have been made under somewhat similar conditions elsewhere. In the case of the catchment area of Long Island supplying Brooklyn, Mr. Allen Hazen has estimated that about 900,000 gallons per square mile per day can be recovered. This corresponds to about 43 per cent of the total annual rainfall which, in that vicinity, is about 44 inches. The soil of Long Island is sandy and conditions are exceptionally favorable for the collection of ground water. Mr. Hazen states that in other localities where the rainfall is the same, the safe yield might not exceed 500,000 gallons per square mile per day, and in some parts of the country with the same rainfall the yield might fall as low as 100,000 gallons per square mile per day.

Mr. Herbert Wilson in his book on "Irrigation Engineering" in speaking of water from subterranean galleries says: "It might be generally stated that the amounts of water to be derived by such means are very limited, and do not approach those claimed by the advocates of so-called underflow." He goes on to give figures and states that the Spring Valley Water Company of San Francisco gets the following from one gravel bed:

Gravel bed area = 1,200 acres.
Watershed area = 300 square miles, 192,000 acres.
Into gravel beds there are 91 wells, which furnish 36 acre-feet per day.

This amounts to about 12,000,000 gallons per day, or about 40,000 gallons per square mile per day. The maximum possible underground supply from sources supplied by these watersheds has been carefully studied by a number of eminent authorities and estimated to be between twenty and thirty million gallons per day or about 80,000 gallons per square mile per day.

In commenting on the flow of water from underground storage, Mr. A. P. Folwell gives figures for the Connecticut River showing that the least flow of that stream is equivalent to about .05 second feet per square mile of watershed. This is maintained for probably at least a month of no rainfall and for about three months when the

rainfall is no more than enough to equal evaporation and requirements for vegetation. This is equivalent to 32,400 gallons per square mile per day and for a watershed of 45 square miles (the approximate size of the San Pablo watershed) would amount to about one and one-half million gallons per day. In this case, only the water escaping through springs is considered and no doubt a somewhat greater supply could be recovered, if wells or galleries were driven into the gravel beds.

As yet there has been no attempt to make the water spread out and cause more of it to enter the gravel storage beds. If such means were adopted, it would undoubtedly make it possible to recover more, and would make available much of the water which now runs to waste.

The average annual rainfall in the vicinity of Richmond is about 25 to 26 inches. According to a standard approximate empirical formula for the coast range mountains of California, that the percentage of rainfall which occurs as runoff is approximately equal to the number of inches of rainfall (for example, if there were 25 inches of rainfall there would be 25 per cent of this or 6¼ inches runoff), there would be an average of about one-fourth of the total rainfall in the vicinity of Richmond which would occur as runoff, the remaining three-fourths being lost by evaporation and otherwise. Of this 25 per cent of the rainfall which occurs as runoff, it is probable that at least one-half in a normal season finds its way through surface channels to the bay and is lost. It will be assumed for the purpose of this analysis that the remaining one-half of the runoff seeps into the ground and the gravel beds as ground water and that one-half of this ground water can be recovered by wells or galleries, or other practical means of collecting it. Most of the above assumptions are quite arbitrary, but it is believed will give a figure representing the maximum yield from underground sources, which can be maintained. Estimating, then, that the maximum production from underground sources is one-quarter of the normal runoff, or one-sixteenth of the annual rainfall, a yield will be obtained equal to about 75,000 gallons per day for each square mile of watershed.

San Pablo Cone.

The total area of the San Pablo Creek watershed above Richmond is about 29,000 acres, or 45 square miles. Estimating a yield as above deduced of 75,000 gallons per square mile, this would indicate the maximum practical yield of the underground sources of the San Pablo Cone of about 3,400,000 gallons per day. This should be taken as the average yield. If maintained it would require during a series of dry seasons the withdrawal of stored underflow with consequent lowering of the ground water level, possibly to such an extent as to cause deterioration in the quality of the water.

Wild Cat Cone.

The area of the Wild Cat watershed above Richmond is about 6,000 acres, or less than 10 square miles. Estimating the maximum probable yield through the development of ground water supplied in the gravels in the lower portions of the creek at the same rate as deduced above, the maximum yield which could be sustained would be

about 750,000 gallons per day. At present this source is being drawn upon by wells of the Peoples Water Company to the extent of something less than two-thirds of the above estimated amount. It is doutful if this source could be developed so as to greatly increase this amount without permanently lowering the water plane.

Pinole Creek Cone.

The area of that portion of the watershed of Pinole Creek contributing to its gravel cone is about 10,000 acres, or 16 square miles. On the same basis used above, the ultimate amount of ground water that could be consistently uncovered would not exceed 1,250,000 gallons per day. The cost of developing this water for use in Richmond would be materially increased by the 7-mile pipe line through which it would have to be brought into the district.

Richmond Wells—(Marginal Plain.)

The hillside area tributary to wells that might be sunk along the base of the Potrero hills is not more than 1,200 or 1,300 acres, or about two square miles. Based on the previous assumptions, the maximum sustained draft which could be maintained on underflow supplied from this source, would not exceed about 150,000 gallons per day. If we assume the entire area west of the crest of the hills east of Richmond and south of Wild Cat Creek, as available for furnishing water underflow, we would have a total of about 7,000 acres, or about 11 square miles, which on the above basis would be capable of supplying about 800,000 gallons per day. The wells in this area are now being called upon to furnish about this amount. The general correctness of this method of estimating can well be inferred from the fact that the present draft from wells in this area is so nearly equal to their maximum yield that the water surface is frequently drawn below sea level, and at times the water is decidedly brackish, containing excessive amounts of chlorine, as shown by the analyses given.

SUMMARY.

A summary of the theoretical estimated yield of ground water in the vicinity of Richmond in the various available sources is as follows:

Table No. 30—Theoretical Estimate of Underground Water Yield.

Sources	Estimated Maximum Yield
San Pablo Cone	3,400,000 gals. per day
Wild Cat Cone	750,000 gals. per day
Pinole Cone	1,250,000 gals. per day
Marginal Plain	800,000 gals. per day
Total	6,200,000 gals. per day

Comparable with this figure is Table No. 14 of Chapter II, which shows that the present production of wells within this district is about 3,400,000 gallons per day. It is hardly believed to be practical to increase this, 2,800,000 gallons per day (about the theoretical limit given above) without frequently getting water of undesirable quality.

CHAPTER No. VI.
Possible Production of Water from Surface Runoff

Considerably over half of the Richmond Municipal Water District is mountainous, comprising the watersheds of Wild Cat and San Pablo Creeks, and a portion of that of Pinole Creek. These three creek are approximately parallel, running northwesterly to the Bay. On each of these creeks, especially on San Pablo Creek, which is the largest, there are good reservoir sites. By constructing dams across the valleys at these sites, it is possible to impound surface runoff and develop a large amount of water for use in the district.

SAN PABLO CREEK PROJECT.

Description of Watershed—Topography.

The San Pablo dam site is about 7 miles from the mouth of the creek. About 70 per cent of the entire watershed is above the dam site. The topography of this 70 per cent which would contribute surface runoff is generally rough, with somewhat rounded hills in the lower portions, and steep rocky slopes and deep rocky canyons in the upper portions. Elevations range from 175 feet above sea level in the creek bottom at the dam site to 1,400 feet along the northeasterly boundary, and to 1,840 feet near the summit of Grizzly Peak.

The floor of the reservoir site is comparatively flat, between elevation 200 and 250. Steeper slopes in general begin at about the latter elevation. Eighteen per cent of the entire watershed is above the 1,000 feet contour, and over 50 per cent above the 700 feet contour. Assuming the surface of the reservoir at high water elevation or 280 feet the average elevation of the entire watershed is about 755 feet. Table No. 31 shows the total area above each 100 feet contour and the total area between the 100 feet contours.

Table No. 31—Elevation of San Pablo Watershed Above Dam Site.

Above elevation	Area ac.	Area bet. contours	Per cent of total above elev. given	Per cent of total
170	20,700		100	
		500		2.5
300	20,200		97.5	
		1,700		8
400	18,500		89.5	
		1,900		9.5
500	16,600		80	
		2,400		11
600	14,200		69	
		3,000		15
700	11,200		54	
		2,970		14
800	8,230		40	
		2,270		11
900	5,960		29	
		2,180		11

Above elevation	Area ac.	Area bet. contours	Per cent of total above elev. given	Per cent of total
1,000	3,780		18	
		1,500		7
1,100	2,280		11	
		640		3
1,200	1,640		8	
		610		3
1,300	1,030		5	
		410		2
1,400	620		3	
		620		3
1,800	0		0	
		20,700		

Average elevation 755 feet.

Character of Surface.

In the lowlying lands at the delta of the San Pablo Creek, and in the flat bottom of the narrow valley higher up, the surface material is ordinary alluvial and gravel deposits washed from the adjacent hillsides. It is probable that bedrock is comparatively close to the surface anywhere along the portion of the creek valley in the mountains, so that it is possible for but a limited amount of underflow to travel down the valley. On the higher slopes the rocky hills are overlaid generally with a thin covering of soil. In the winter and spring this supports a sparse growth of wild grass, sufficient for pasturage until it dries up in the summer. On the more sheltered slopes and in the canyons there is a scattering growth of underbrush and deciduous trees.

Area.

The total area of the watershed above the site of the proposed dam is 20,700 acres, or about 32 square miles. The area of water surface in the reservoir will be about 400 acres or about 2 per cent of the entire watershed. Of the watershed above the dam site, about 13,700 acres or about 66 per cent is outside of the boundaries of the Richmond Municipal Water District. Twelve thousand acres, or about 75 per cent, has been acquired by the Peoples Water Company. In these holdings are included the reservoir site and much of the more desirable land along the creek. The balance is composed of a large number of farms of various owners.

Population.

The country generally is rough and uninviting, so that only the lower and flatter areas along the creek bottoms are inhabited. Here a number of farms are under cultivation, supporting a scattered rural population, chiefly engaged in stock raising. On the land owned by the Peoples Water Company near the reservoir site, there are about a dozen farm houses, most of which are unoccupied. The latest U. S. Geological Survey map of this region, published in 1910, shows 56 houses in the entire watershed. It is probable that the number has not materially changed in recent years, or if anything, it has decreased. Assuming an average number of five occupants in each house as the total population, it is estimated that above the dam site there are about 250 inhabitants on the watershed, or an average of less than 8 persons per square mile.

Improvements.

The only improvements of importance in the district are farming houses, most of which are of old timber frame construction, of no great value. If the average cost of the 56 places is estimated at $750 each, the total value of improvements of the watershed above the dam site amounts to about $42,000.

RUNOFF.

Rainfall.

As no complete records of rainfall on the San Pablo watershed are available for study, those of the Berkeley and Oakland stations of the United States Weather Bureau have been used, as approximating most closely the conditions on the watershed.

The records for the Berkeley station from 1887 to 1913 show an average annual, and an average seasonal rainfall of 26.07 inches. The maximum seasonal rainfall during the same period was 46.00 inches, occurring in 1889-90. The minimum seasonal rainfall was 14.40 inches in 1897-98. The season of 1911-12 was a close second, with 14.73 inches. The 1912-13 season was third with a rainfall of 15.63 inches. During the 26 seasons for which records are complete, in only 6 of them was the rainfall below 20 inches.

The records of the Oakland station of the Bureau extend back to 1874, or 13 years further than those of Berkeley. The average seasonal and annual rainfall during the period 1874 to 1913 was 24.07 inches. The maximum seasonal rainfall during this time was in 1889-90 with a rainfall of 45.71 inches. In only one other season did the rainfall exceed 33 inches; that was in 1894-95 when it was 36.89 inches. The minimum seasonal rainfall occurred in 1911-12 and was 11.58 inches. The second lowest was in 1912-13 and was 11.88 inches. During the 38 years considered, in 10 seasons the rainfall was below 20 inches. This is during 26 per cent of all the seasons.

At both the Berkeley and the Oakland stations, during the period from 1887 to date, the smallest rainfall for two consecutive seasons occurred during the two seasons just past. At Berkeley the total rainfall during the seasons 1911-13 was 30.36 inches, while at the Oakland station the total for the same two years was 23.46 inches. Other two-year droughts that have been recorded within the periods for which there are records, show that at only one other time since 1887 has the rainfall at Berkeley for two consecutive seasons fallen below 40 inches, that was in 1887-89, when it was 35.78 inches. In comparatively few cases has the total for two consecutive seasons fallen short of 50 inches. Besides the 1911-13 drought the Oakland records show four two year periods with a total rainfall less than 40 inches as follows:

1881-83	total	rainfall	35.35	inches
1886-88	"	"	35.65	"
1887-89	"	"	38.47	"
1897-99	"	"	38.60	"

The present drought with only 23.46 inches in two seasons not only breaks all previous records, but is less than two-thirds of the lowest rainfall previously recorded for any two consecutive seasons. The

most severe three-year drought before the current three-year period occurred in Oakland during the three seasons 1886-89, when the rainfall for three consecutive seasons was 57.02 inches, averaging 19.01 inches per season. During the three years just passed, this record has been exceeded in Oakland and probably in Berkeley. The total rainfall in Oakland during these three years was 51.22 inches, being over 10 per cent less than the next lowest, and more than 20 per cent less than any other series of three seasons. This is in spite of the fact that the rainfall during 1910-11 was 10 per cent above the normal. If there should be another dry season this year, with rainfall below normal, it would throw the total for three consecutive seasons much farther below the most severe droughts previously recorded, and would make the securing of water supplied from surface runoff even more problematical.

It is well known that the amount of rainfall differs at different elevations, increasing as the elevation rises. The rainfall is assumed in these studies to vary uniformly with the elevation, increasing at a rate of .7 inch per annum for each 100 feet increase in elevation.

The elevation of the Oakland station at which the gaugings given above were made is 36 feet; that of the Berkeley station 320 feet, a difference of about 300 feet. The annual average rainfall differs by about two inches, or approximately, in accordance with the above assumptions.

In studying rainfall and probable runoff from the San Pablo watershed, the records of the Berkeley station have been used after correcting for differences in elevation according to the above-named rate of .7 inches per year, per 100 feet rise.

Relation of Rainfall to Runoff.

Only a relatively small percentage of the rain that falls on a watershed ever finds its way into the streams and appears as runoff. The proportion that this runoff bears to the total rainfall depends on a number of factors, such as the topography and character of soil in the watershed, the general climatic conditions, including total amount of rainfall, distribution of the rain over the season, temperature and wind velocity.

If the topography is rough and the watershed generally has steep slopes, the rainfall will be quickly delivered to the streams and the runoff will be proportionately large. If the slopes are bare and rocky, or with a thin covering of soil, the proportion of runoff will be greater than for sandy or gravel soil.

The topography of the upper portions of the San Pablo watershed is rough and in general the slopes are steep and rocky with a thin covering of earth. As above stated, this is favorable for a large proportion of runoff.

The distribution of the rainfall throughout the season is very important. If it all falls within a comparatively short period, the runoff is much larger, than for the same amount of rainfall distributed over a longer time. The proportion of the runoff to the rainfall also varies more or less directly with the total rainfall, that is, with a greater rainfall, a larger proportion of it will run off. Therefore, the runoff increases or decreases much faster than the rainfall itself.

The distribution of the rainfall over the season is shown by the average figures for each month during the 25 years from 1887 to 1912 as given in the Weather Bureau reports for Berkeley as follows:

January	5.65	July	.02
February	4.35	August	.04
March	4.79	September	.57
April	1.53	October	1.48
May	1.11	November	.54
June	.21	December	4.20

Nearly 80 per cent of the annual rainfall occurs during the four months of December, January, February and March. This is a condition conducive to large runoff because most of the water either falls so rapidly that it cannot soak into the ground or it falls on ground already in a saturated condition.

Estimate of Runoff.

The only accurate way of estimating the runoff is by means of surface measurements giving continuously the flow throughout the season for a number of years. No complete records of this kind are available for the watersheds within the Richmond Municipal Water District, hence it becomes necessary to make an approximate estimate based upon the measured runoff on adjacent watersheds.

Mass curves showing the probable runoff from 1874 to 1913 from the San Pablo and Pinole watersheds above the proposed dam sites are shown on Diagram No. 9. These curves are made by platting the runoff as calculated from the measured rainfall taken from the records of the U. S. Weather Bureau. From 1887 to 1913 the rainfall records for Berkeley were used as a basis and a correction of .7 inches per 100 feet elevation was added or substracted for each 100 feet above or below 320, the elevation of the Berkeley station. For the 13 years preceding 1887, the records for Oakland were used with similar corrections. The runoff has been estimated from the widely used approximate rule that the percentage of rainfall which occurs as runoff is equal to the number of inches of annual or seasonal rainfall. Where this rule has been checked up on watersheds of a charcter similar to those under consideration, it has been quite generally found to be conservative and to give results less than the measured runoff. With a seasonal rainfall of 25 inches the runoff would be estimated as 25 per cent of 25 inches or 6¼ inches. The rainfall and runoff obtained by this method are shown in the following table:

Table No. 32—Estimated Rainfall and Runoff of the San Pablo Watershed Above Dam Site—Area of Watershed, 20,700 Acres.

Season	Seasonal Rainfall	Rainfall corrected for elev.	Computed runoff in inches	Computed runoff in M. G.	Computed impounded M. G.	Mass quantity M. G.
1874-75	21.57	26.60	7.08	3,980	3,495	3,495
1875-76	28.56	33.59	11.28	6,340	5,855	9,350
1876-77	12.33	17.36	3.01	1,690	1,205	10,555
1877-78	32.33	37.36	13.96	7,850	7,365	17,920
1878-79	23.47	28.50	8.12	4,560	4,075	21,995
1879-80	23.84	28.87	8.33	4,680	4,195	26,190
1880-81	31.76	36.79	13.54	7,610	7,125	33,315
1881-82	18.13	23.16	5.36	3,070	2,585	35,900
1882-83	17.22	22.25	4.95	2,780	2,295	38,195
1883-84	31.10	36.13	13.05	7,330	6,845	45,040
1884-85	17.95	22.98	5.28	2,970	2,485	47,525

Season	Seasonal Rainfall	Rainfall cor. rected for elev.	Computed runoff in inches	Computed runoff in M. G.	Computed impounded M.G.	Mass quantity M. G.
1885-86	32.21	37.24	13.87	7,790	7,305	54,830
1886-87	18.55	23.58	5.56	3,120	2,635	57,465
1887-88	17.49	20.53	4.22	2,370	1,885	59,350
1888-89	18.29	21.33	4.55	2,558	2,073	61,423
1889-90	46.00	49.04	24.07	13,530	13,045	74,468
1890-91	23.96	27.00	7.30	4,100	3,615	78,083
1891-92	23.38	26.42	6.98	3,925	3,440	81,523
1892-93	29.91	32.95	10.85	6,100	5,615	87,138
1893-94	26.65	29.69	8.83	4,960	4,475	91,613
1894-95	39.01	42.05	17.70	9,950	9,465	101,078
1895-96	27.72	30.76	9.45	5,310	4,825	105,903
1896-97	28.94	31.98	10.22	5,740	5,255	111,158
1897-98	14.40	17.44	3.05	1,715	1,230	112,388
1898-99	27.66	30.70	9.43	5,300	4,815	117,203
1899-1900	25.34	28.38	8.05	4,525	4,040	121,243
1900-01	25.11	28.15	7.92	4,450	3,965	125,208
1901-02	25.86	28.90	8.35	4,690	4,205	129,413
1902-03	25.41	28.44	8.10	4,550	4,065	133,478
1903-04	33.59	36.63	13.42	7,550	7,065	140,543
1904-05	29.35	32.39	10.49	5,900	5,415	145,958
1905-06	27.75	30.79	9.47	5,320	4,835	150,793
1906-07	31.87	34.91	12.20	6,860	6,375	157,168
1907-08	19.16	22.20	4.93	2,770	2,285	159,453
1908-09	31.55	34.59	11.95	6,710	6,225	165,678
1909-10	22.28	25.32	6.41	3,600	3,115	168,793
1910-11	30.41	33.45	11.19	6,290	5,805	174,598
1911-12	14.73	17.77	3.16	1,775	1,295	175,893
1912-13	15.63	18.04	3.26	1,830	1,345	177,238
		29.08	8.95	5,029	4,545	

NOTE: Correction for rainfall in —0.7 inches per 100 feet elevation. Runoff by empirical formula. Evaporation taken as 54 inches per annum over water surface. Records from 1874-1886 taken from the Oakland station and from 1887-1913 are taken from the Berkeley station of the U. S. Weather Bureau.

The figures given in the foregoing table have been used in platting the mass curves of runoff shown in Diagram No. 9. For platting these curves monthly variations were not used, but only the computed seasonal runoff. As the object in platting these curves was to use them in studying the proposed San Pablo Reservoir, they were corrected for evaporation from the average surface of the reservoir.

Required Storage.

The height of the curves at any point, represents the total amount of water corrected for evaporation on the surface of the proposed San Pablo reservoir that would have occurred as runoff at the dam site from the beginning of 1874 to the date represented by the point. That is, it represents the total amount that could have been impounded by the proposed dam and delivered from the reservoir.

The straight lines radiating from the origin at the lower lefthand corner represent assumed rates of delivery, while an average of the curve represents the average rate of accumulation. It is obvious that the ultimate capacity of a watershed to deliver water is equal to the rate shown by the straight line which most nearly approximates the general

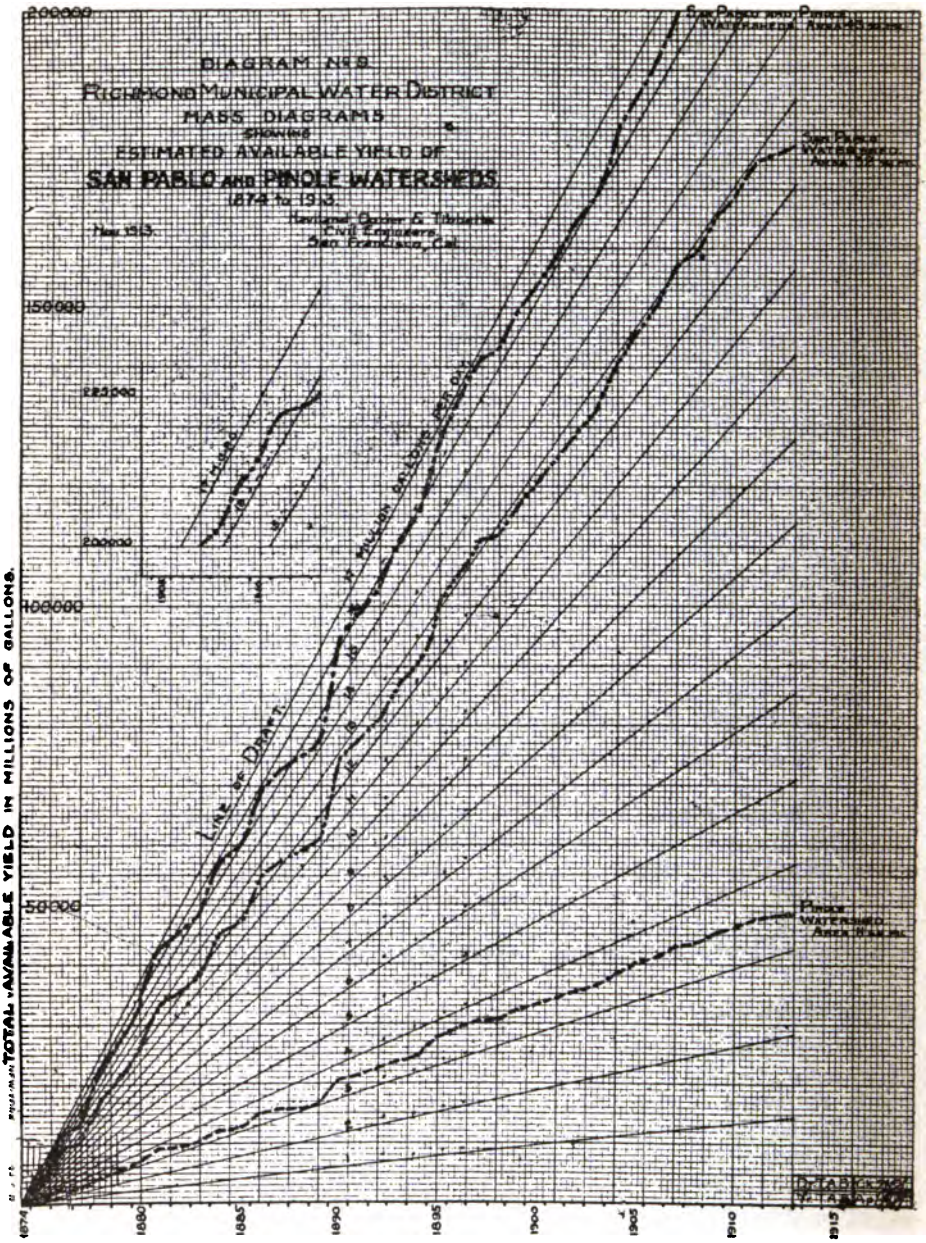


DIAGRAM No 2.
RICHMOND MUNICIPAL WATER DISTRICT
MASS DIAGRAMS
showing
ESTIMATED AVAILABLE YIELD OF
SAN PABLO AND PINOLE WATERSHEDS.
1874 to 1913.
Nov. 1913.
Line of Demand
TOTAL AVAILABLE YIELD IN MILLIONS OF GALLONS.
1874
1880
1885
1890
1895
1900
1905
1910
1915

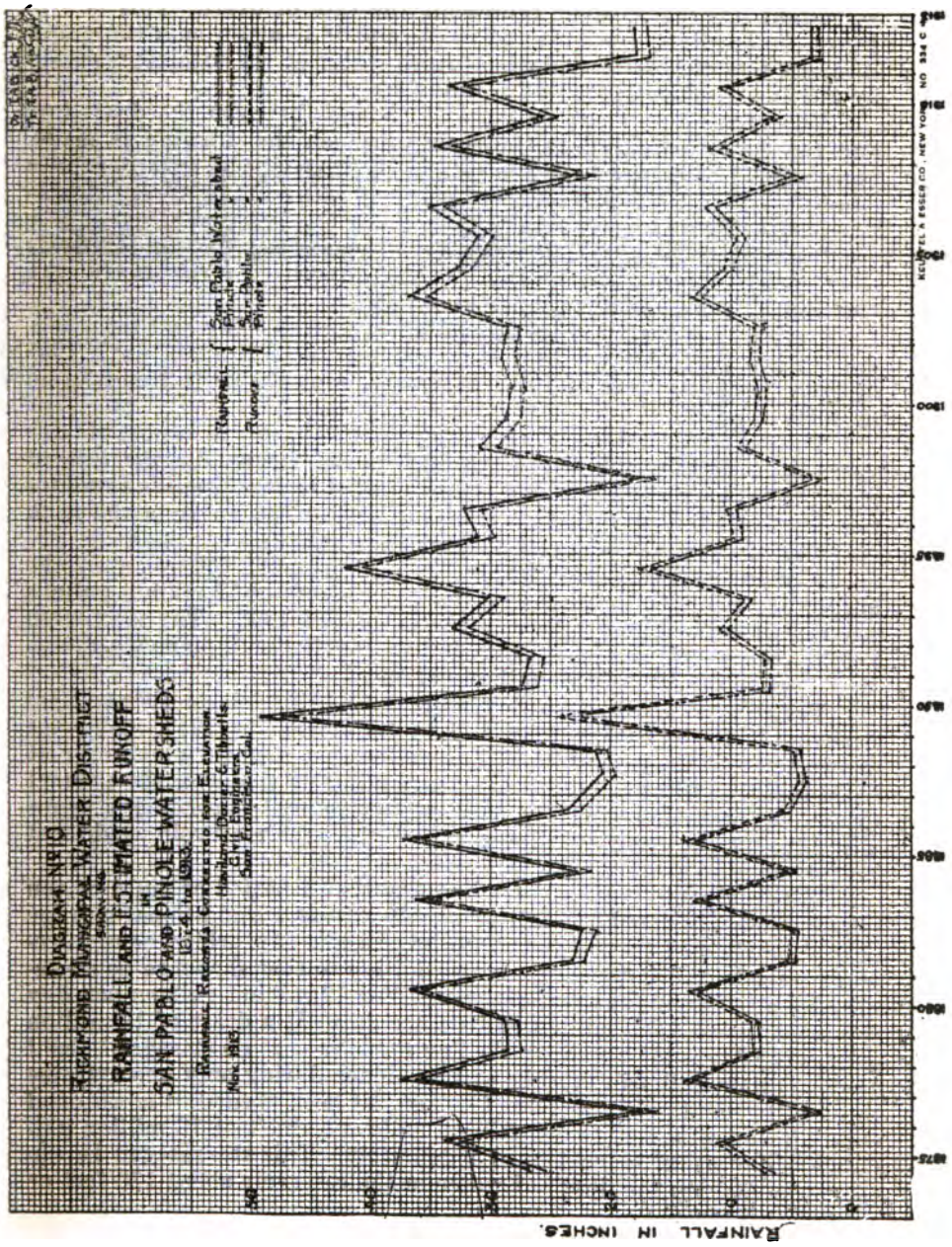


DIAGRAM NO 10
RECLAMATION AND WATER DISTRICT
SHOWING
RAINFALL AND ESTIMATED RUNOFF
IN
SAN PABLO AND PINOLE WATERSHEDS
1874 to 1915
Rainfall Records Compiled from Records
Kept by Observers & Others
Runoff Records Compiled from Estimates
Made by Engineers of
San Francisco Water Dept.
Nov. 1915
Rainfall
Runoff
RAINFALL IN INCHES.
1875
1880
1885
1890
1895
1900
1905
1910
1915

direction of the mass curve. To determine the storage necessary for any chosen rate of delivery, start at one of the peaks of the curve with a straight line whose slope represents the rate of draft. This is projected forward from any of the peaks and if it again cuts the curve it means that the watershed can furnish water at the rate represented by the line if sufficient storage is provided.

The greatest ordinate or vertical distance between the draft line and the curve measured to the scale to which the drawing is made, represents the minimum storage required and should be exceeded by a quantity arbitrarily taken at 300 days or 10 months' supply at the proposed rate of draft.

Thus on the diagram for San Pablo watershed the line of draft most nearly approximating the general direction of the curve, lies between 12 and 13 million gallons per day.

Assuming a draft rate of 12 million gallons per day and the reservoir full in the spring of 1897, it would not be full again until 1905 or 1906. In the spring of 1907 the reservoir would be full and again in 1909.

The minimum storage necessary to tide over a series of dry years such as those from 1897 to 1905 is determined by the largest ordinate between the curve and a line parallel to the 12 million gallons per day draft line and starting from the peak of the curve at the peak of 1907. This would be about 4,000 million gallons.

A more critical period occurs in 1886 to 1890. Starting in the spring of 1886 with the reservoir full and a draft of 12 million gallons per day it will be full again in the spring of 1890. The maximum height between the mass diagram and the draft line indicates a necessary storage of about 7,000 million gallons.

The current series of years beginning in 1910-11 is another critical period. If the reservoir were full in the spring of 1911, and were drawn upon at the rate of 12 million gallons per day, then a storage of 6,000 million gallons would have been required to tide over the present drought. Assuming that the current season and suceeding seasons will have an average rainfall and runoff, then the reservoir would not be full again for more than ten years.

In this climate it frequently happens that a period of eight or ten months passes without rainfall or runoff so that an additional storage should be allowed to tide over this dry season. An arbitrary requirement is made of 300 days' supply in addition to that shown to be necessary by a study of the mass diagram. For 12 million gallons per day this amounts to 3,600 million gallons per day. If a draft of 12 million gallons per day is to be made on the San Pablo reservoir a storage of about 10,600 million gallons would be ample. Since during only one extreme drought in the last 40 years has this amount been needed, it is assumed that with a storage of 10,000 million gallons a draft of 12 million gallons per day could be continued indefinitely. This storage can be obtained by making the depth of water in the reservoir about 130 feet or at elevation 290.

For the draft required to supply the immediate needs of the district a much smaller storage is required and for reasons explained later in this chapter it seems best at this time not to carry the dam higher than sufficient to hold the water at elevation 280. This will

give a storage capacity of nearly 8,000 million gallons in the reservoir, and will probably be sufficient to enable the watershed to consistently furnish 10 to 11 million gallons per day. When the demands for water exceed this, the dam can be raised or the Pinole tunnel project carried out as explained in this chapter.

Evaporation.

Not only does the runoff into the reservoir depend on the rate of evaporation on the watershed, but the water stored is greatly decreased by the continued evaporation from the surface of the reservoir itself. No records of evaporation at the immediate site of the proposed reservoir are available at this time, but numerous tests have been made at other places similarly located and a fairly accurate idea may be had from them as to what is to be expected here.

Evaporation depends chiefly on three conditions, wind velocity, humidity, and temperature, here named in the order of their relative importance.

Studies of prevailing winds in the San Francisco Bay region are summarized in Diagram No. 1 of Chapter No. 1 showing prevailing direction, and Diagram No. 2 showing wind velocities.

The mean annual temperature at Berkeley for 25 years has been 55.7 degrees. The maximum for 15 years was 101 degrees and the minimum was 29 degrees. The mean maximum temperature for 15 years was 63.1 degrees and the mean minimum temperature for the same period was 48.6 degrees. These figures show a very equable climate with a variation in 15 years of only 14.5 degrees between the mean lowest and the mean highest temperatures.

Measured Runoff.

The only record of measured runoff from the San Pablo watersheds is an incomplete set of gaugings by the Peoples Water Company made at the site of the proposed dam for the four seasons, 1905-06, 1906-07, 1909-10, 1910-11. The first two of these do not cover the entire season, but only that portion of it during which the greater part of the runoff occurred. These figures have been corrected for evaporation from the average surface of the proposed reservoir to give the amount of water that could have been impounded during these seasons. They are then compared with the runoff for the same seasons as computed by the empirical formula previously used and the variation noted. It will be seen that in every case the computed runoff is less than the measured runoff, the variation running from 22 to 53 per cent. The latter very large variation occurs in the season immediately following the particularly wet season of 1908-09, and it may reasonably be expected that the ratio of runoff to rainfall for this particular season would be above the normal. The general comparison, however, shows that figures computed by the formula are very conservative, and the actual yield is quite probably more than computed. The following table gives the runoff past the dam site for four seasons, as measured by the Peoples Water Company, and comparative computations based on the empirical formula used.

The Berkeley and Oakland rain gauges are located on the southwest slope of the hills directly exposed to the winter storms, whereas the bulk of the San Pablo watershed is separated from the ocean by intervening ranges of hills. For this reason the estimated rainfall of Tables Nos. 32 and 35 would have been decreased were it not for the fact that the runoff estimates thus obtained are still much lower than the measured runoff as shown by Table No. 33. It is likely that the rainfall estimates given herein are too large and the runoff factors too small and the resulting runoff somewhat too small. On the adjacent watershed of San Leandro Creek four years of average rainfall of 22.1 inches measured at one gauge at elevation of 286 feet, situated similarly to the Berkeley gauge, gave a runoff of 35 per cent and two years of average rainfall of 28.1 inches, gave a runoff of practically 50 per cent.

Table No. 33—Comparison of Measured and Computed Runoff Past San Pablo Dam Site.

(Column 3, "Amount Impounded," is obtained by correcting the figures in Column 2 for the seasonal evaporation from the average surface of the proposed reservoir.)

Season	Measured runoff	Amount impounded	Expected daily ave. yield
1905-06 (Part)	8,198,000,000	7,904,000,000	21,650,000
1906-07 (Part)	9,187,500,000	8,893,500,000	24,370,000
1907-08	Dry year, no measurements.		
1908-09	Wet year, no measurements.		
1909-10	6,622,500,000	6,328,500,000	17,340,000
1910-11	7,440,000,000	7,156,000,000	19,600,000

Compared With Runoff as Computed by Empirical Formula.

Season	Computed M. G	Measured M. G.	Difference M. G.	Difference Per cent
1905-06	4,835	8,198	3,363	+41%
1906-07	6,375	9,187	2,812	+30.6%
1909-10	3,115	6,622	3,507*	+53%
1910-11	5,805	7,440	1,635	+22%

*This was just after an exceptionally wet season which doubtless had some effect in increasing the runoff.

STORAGE RESERVOIR.

Location.

The proposed San Pablo reservoir is located about four miles due east of the intersection of San Pablo and Macdonald Avenues. Its relative location with respect to Richmond is shown on Plate No. 1. Following the windings of San Pablo Creek the dam site is about six miles in a general easterly and southeasterly direction from the intersection of Alvarado Street, County Road No. 20, County Road No. 3 and County Road No. 17, at the old town of San Pablo. The reservoir itself lies along the creek with its axis in a general southeasterly and northwesterly direction.

Capacity.

As shown above, if the reservoir were constructed at once to develop the entire runoff of the watershed above the dam, the storage capacity required would be in the neighborhood of 10,000 million gal-

lons. With water 10 feet lower in the reservoir and a capacity of 7,600 million gallons the permissible daily draft is reduced only about two million gallons and the additional water is probably not worth the additional cost.

It would be better, therefore, to build with the capacity of about 7,600 million gallons which would enable a steady draft to be maintained, of about 10 to 11 million gallons per day. There will be sufficient storage capacity to equalize the flow over a series of dry years as bad as the worst that have occurred since 1874.

Area.

The area and capacity of the San Pablo reservoir for the water at given elevations from 160 to 320 feet, are shown by table and diagram on Plate No. 6. With the flow line at elevation 280 feet above sea level, the capacity is about 7,600 million gallons. The superficial area at this elevation is about 590 acres, or 2.85 per cent of that of the watershed. If it is ever desired to raise the water level to 290, thereby getting the full 10,000 million gallons capacity theoretically required for conserving the entire runoff, the area would be about 660 acres, or 3.2 per cent of the watershed.

In order to provide for possible extension for the efficient patrol of the reservoir site, and for the construction of roads and parking, it is proposed that in addition to the reservoir site the district should acquire a strip approximately ¼ of a mile in width entirely around the reservoir and outside of the flow line at elevation 290. This would give a total area, including the reservoir site, of about 1,500 acres. All of this land is now owned by the Peoples Water Company. Twelve ranch houses and groups of buildings lie within this area, four of which are below the proposed maximum water line at elevation 290.

It is quite possible that if this project were worked out it would be found necessary or desirable to acquire a much larger body of land perhaps, even the entire watershed. If this were not done, it is possible that by the construction of dams above the proposed reservoir site, on land otherwise owned, water could be diverted away from the reservoir. It is also possible that the proper patrol of the watershed and the protection of the quality of the water from surface contamination might ultimately require that the entire watershed be acquired and depopulated.

Parking Possibilities.

The site of the dam and reservoir abounds in laurel, oak and other wild ornamental trees that could be preserved and supplemented for parking and beautification. There are a number of eucalyptus trees close by which suggest other possibilities. The County Road traverses the reservoir site from end to end and in the event that the dam is built, the road would have to be moved to higher ground. If located on the wide hill along the east side of the reservoir it could be parked with trees and made a scenic drive. The space below the dam and around the control works and filter building could be planted to lawn and beautified by shrubbery, hedges and ornamental trees. The site is only six miles from the edge of the city of Richmond and it seems probable that it could be developed as a municipal park and recreation ground with trolley service to the city.

PROPOSED DAM.

Location.

At the location chosen for the proposed dam, the site is excellent, except for poor foundation conditions. It is at a point where the valley narrows between two well defined shoulders of the hills with a rounded hill about midway between about half a mile below an important branch of the creek. This site is about 28,000 feet, or 5.3 miles up San Pablo Creek from its crossing of Alvarado Street in the old town of San Pablo. As shown on Plate No. 1, it is directly east of the center of Richmond, being about 3½ miles in a direct line and almost due east from the intersection of Macdonald and San Pablo Avenues. The axis of the dam will be normal to the valley and extend in a general northeasterly and southwesterly direction.

On the northeast side there is outcropping rock in places. In general, the rock appears to be covered by a thin layer of surface soil, supporting a scattering growth of brush. In the bottom, and southwest side of the valley, the soil covering is quite thick and the surface covered with dense brush and in places with large trees. Just below the dam site there is a large level area well adapted for the construction of filtering works, pumping plants or other accessories.

Height.

The lowest point in the creek bed at the dam site is about at elevation 158. The cross section and detailed topography are shown on Plate No. 6. To obtain the theoretically required storage of 10,000 million gallons the water would be held up to elevation 290, but for the construction here proposed it would be held at elevation 280. As the reservoir has a long sweep exposed to southwest winds the crest of the dam should be well above the water surface. A liberal allowance of 12 feet above the high water line puts the top at elevation 292. This would make the maximum height about 134 feet, and the maximum depth of water about 122 feet. The average height of the dam as shown from the cross section would be about 60 feet.

A storage of 6,000 million gallons could be obtained with the water surface at elevation 270 and the crest of the dam to about 285, giving a maximum height of 127 feet, and an average height of 51 feet.

Construction.

As satisfactory rock foundations are not obtainable, estimates for the dam are based on the assumption that it will be an earth embankment with a core wall of concrete or clay puddle carried down to rock. It is proposed to make the crown width 30 feet, and the side slopes 1 on 3 on the water side, and on the rear side 1 on 2½, with two 20-foot berms about 30 feet apart vertically. The core wall will be carried down the entire length of the dam to solid rock. No satisfactory data is available regarding the depth to rock. Borings and tunnels were made by the Peoples Water Company in 1906 or 1907 to investigate this point. The tunnels are still in evidence, and from data available, it is estimated that the depth to rock at the center of the dam will not be less than 70 feet. On the southwest side it will probably exceed 30 or 40 feet, for most of the distance. On the northeast side, however, rock

is very near the surface. The corewall, if of puddle, will be built of a proper mixture of clay and sand, placed in layers and thoroughly puddled until impervious.

Earth Work.

The material at the site of the dam will not be suitable for a homogeneous earth dam, and for this reason a core wall type has been selected. Much of the excavated material will probably be loose rock or earth mixed with rock. It would not be undesirable to place this on the downstream side of the core wall. There is would furnish weight for stability and be loose enough to permit good drainage of the downstream part of the dam.

Masonry Corewall.

Alternate estimates are given herein for a dam built with a corewall of masonry instead of a puddle corewall. In this design the corewall should have a top width of 4 feet, with the top 5 feet below the top of the dam. The side slopes of this corewall will be 15 on 1 on both sides down to the surface of the ground. Below that the corewall will extend down as a cutoff wall with vertical sides to bedrock.

Volume.

The volume of that portion of the dam which lies above the original ground surface will be about 847,000 cubic yards. Two alternate plans call for a corewall of concrete and of clay puddle, respectively. If the design with concrete corewall and cutoff wall is used, the approximate volumes will be as follows:

Earth embankment 824,00 cubic yards.

Concrete corewall 55,700 cubic yards.

Excavation 32,800 cubic yards.

If the corewall is built of puddle, the approximate volumes are as follows:

Earth embankment 785,600 cubic yards.

Puddle 123,800 cubic yards.

Excavation 62,400 cubic yards.

Foundations.

The probable depths to rock are given in a previous paragraph. Before constructing the earth fill, the foundation of the dam should be carried down to solid rock at the corewall trench and all seams in the rock carefully cleaned and filled. The earth work and foundation should be stripped of surface soil, brush, trees and roots, and thoroughly cleaned and plowed in order that a good junction may be formed between the earth embankment and its foundation.

Spillway.

The spillway will consist of a concrete weir 200 feet long, over which the water spills into a concrete flume. The flume is carried past the north end of the dam, and far enough below so as not to

endanger the safety of the embankment. The spillway weir is designed for a head of 3 feet, which will enable it to discharge 3,500 second feet, or much more than the maximum flood flow, which could be contributed by the watershed above, after being subjected to the restraining influence of the large superficial area of the reservoir site.

Intake.

The intake will be controlled by means of a circular concrete tower with gates at different elevations, and operated from above. The tower will be connected with the nearest point on shore by a small truss footbridge. The tower will have a total height of about137 feet, and the bottom will be under a head of over 120 feet. The outside diameter will be 20 feet and the walls will be of reinforced concrete, 24 inches thick at the bottom and somewhat less near the top. The foundation will be carried down to a firm bearing, and designed as a spread footing about 30 feet in diameter. Gates will be put in at several elevations, to make it possible to draw off water at different depths.

Outlet.

From the intake tower base will extend a short outlet tunnel through the shoulder of the hill near the south end of the dam. It will be a small pressure tunnel concrete lined and about 950 feet long. It will be connected with a pipe line leading to the filters.

Possible Extensions.

Two courses are open for possible extensions, to raise the dam and enlarge the reservoir, or to connect with Pinole reservoir by tunnel and pipe line as discussed in the latter part of this chapter.

Another possible means of increasing the yield would be to divert to this reservoir or to the San Pablo-Pinole reservoir system a portion or all of the runoff from Wild Cat Creek. The yield could probably be increased 50 per cent by these means.

FILTRATION WORKS.

Need of Filtration.

The increasing emphasis placed upon the sanitary quality of public water supplies will probably make it eventually necessary to filter all water produced from surface sources. To guard against the danger of contamination, in unfiltered water, it is necessary to practically depopulate the watersheds. Where watersheds are so close to large cities as those of the Richmond District, it is hardly thought to be a sound economic policy to attempt this. Even if it were accomplished, the danger of pollution from transients, outing and picnic parties, etc., is sufficiently great to justify filtration. There are few surface supplies in this country where the necessity or advantage of filtration is not recognized, or at least strongly advocated. The few exceptions are mostly western cities, deriving their supply from high barren mountainous areas, such as the proposed Hetch Hetchy project for San Francisco.

The acquisition by the Richmond Water District of the entire watersheds is not advocated because of the great cost, though it is recognized that this might be necessary. Even if this were done, the water should

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be filtered, and, of course, the necessity for filtration is much greater if an increasing population is allowed to reside on the watershed.

The cost of filtration is so low and the danger of contamination of a stream flowing off a populated watershed is so great, that there should be no question of the advisability of filtering the water. The cost of filtration would probably not exceed 1c to 1½c per thousand gallons, while the cost to a community of having an unsafe supply or one subject to suspicion will undoubtedly be far greater.

Improvement of Water.

For the surface supplies of the Richmond District filtration plants are recommended primarily to protect the sanitary quality of the water. This result could easily be accomplished with certainty, especially if used, where thought desirable, in conjunction with sterilization with hypo-chlorite of lime. This would not be the only benefit from filtration, however. The surface supply would be somewhat turbid, even after settlement in a large reservoir. Where impounded for long periods in an open reservoir in a climate such as that in California the growth of algae is very apt to produce disagreeable tastes or odors. The water is liable to be colored both from the turbidity and the vegetable growths. Filtration could easily remove all of these objectionable features and produce a water not only safe from a sanitary standpoint, but clear, sparkling, odorless and otherwise attractive.

Capacity.

The first installation of filters should be capable of providing for the maximum probable amount which might be used in the immediate future, estimated at six million gallons per day. The general design and construction should be such that extensions can be readily made by the addition of new units as required until the capacity of the filtration plant is brought up to the ultimate yield possible to obtain from this source. This should be a maximum of 12 million gallons per day, or if additional water were diverted from other sources, perhaps of 15 million gallons per day.

Design.

The reservoir will be used not only to impound the runoff from the watershed, but will also act as a distributing reservoir for the district. For this reason, in order to get the best heads available without pumping, and to get the benefit of fluctuations in the level of the reservoir, it would be best to install the filters as pressure filters. Various objections have been offered against pressure filters, and they are not very widely used, but it is deemed better practice in this case to use them rather than either to pump all the water to a higher elevation or to lose the difference in head due to changes in level of the reservoir.

Filters of this type are now in satisfactory use in both San Francisco (Lake Merced) and the San Diego water supplies. The filtering medium of sand is contained usually in large horizontal steel cylinders inserted in the main conduits, and operating under the same pressure. In any other type of filters, the water is treated with a coagulent before reaching the filtering surface. The filters are cleaned or washed by

reversing the flow of water through them, usually with either mechanical agitation or the use of compressed air. A small loss of head is occasioned by the passing of the water through the filters.

Cost of Operation.

The cost of operation of rapid filters of the type proposed here has been found to vary from $8.00 to $15.00 per million gallons of water treated. The cost of filtration is very small compared to the other items of cost and will not usually be more than about 5 to 10 per cent of the total cost of the water as supplied to the consumer.

Pumping Plants.

It is assumed that the variation in level of the reservoir will not be so great that adequate pressure for fire protection will not be furnished at all times. For this reason pressure filters are to be put in to conserve all the head there is. Pumping plants will not, therefore, be a part of the first installation. In case the draft increases so that the level of the reservoir falls very low it may be found necessary to pump during part of the year. The heads against which such pumping plant would operate would be small and neither the first cost nor the cost of operation are very important.

Coagulation Basins.

Owing to the long subsidence furnished in the reservoir, only a short period of coagulation would be desirable. The coagulation basins, if built, would be small and the water would be passed through them at a rather high rate. They are inconvenient with this type of filter and would probably be omitted altogether.

Filtered Water Reservoir.

A filtered water basin of two to four millon gallons capacity will be built on the hills west of Richmond. This will also act as a balancing reservoir. As before stated, it may be necessary, late in the season, of especially dry years, to pump the water into the system against this reservoir as a standpipe.

PINOLE CREEK WATERSHED.

Description of Watershed—Topography.

The Pinole Creek watershed has the characteristic steep slopes and rocky hills found in adjacent sections in this vicinity. Flat areas of small extent are found along the creek beds, but by far the greater proportion of the area is rough hills ranging in elevation from 300 to 1,200 feet above sea level. The elevations of the flatter creek bottom portions, range from elevation 200 feet at the dam site to about 500 feet at the upper end of the valley.

About 3½ per cent. of the entire watershed is above elevation 1000 feet, and about half of it is above elevation 600 feet. The average elevation is 595 feet.

Table No. 34—Elevations of Pinole Watershed Above Dam Site.

Above Elevation.	Area.	Area bet. Contours.	Percent of Total Above Elevation Given.	Percent of Total.
170	6,930		100%	
		30		.4
200	6,900		99.5	
300	6,350		92	
		550		7.5
		1,020		15.0
400	5,330		77	
		920		13.0
500	4,410		64	
		980		14.5
600	3,430		49.5	
		1,070		15.5
700	2,360		34	
		990		14.0
800	1,370		20	
		860		12.6
900	510		7	
		268		3.9
1,000	242		3.5	
		242		3.5
1,100			0	

Average elevation 595 feet.

Character of the Surface.

The rocky slopes of the higher altitudes are for the most part bare, or have a thin covering of soil. The lower flats are limited in extent and are sandy, gravel and alluvial deposits, washed down from the adjacent hills. These flatter areas are cultivated as farms and hold a limited population on the watershed. The higher slopes are bare of vegetation except in the spring when they support a growth of wild grasses and during that time and the following months they are used for pasturing stock.

Area.

The total area of the watershed draining into the proposed reservoir is 6930 acres, or about 11 square miles. The area of the proposed reser voir is 275 acres, or 4 per cent. of the entire watershed.

Population.

Only the portions near the creek beds are habitable. In these a number of farms have been developed, and a number of families make their homes. The United States Geological Survey maps of this section, published in 1910, show 14 houses on the watershed. Assuming 5 persons per farmhouse, the total population on the watershed is probably about 70. This is an average of 6.4 persons per square mile.

Improvements.

At the rate of $750 each for the improvements on the 14 places mentioned above, the total valuation of improvements would be $10,500.

RUNOFF.

The estimated rainfall and runoff from the Pinole Watershed is shown by the following table No. 35.

Rainfall.

The same figures for rainfall were used for this watershed as for the San Pablo watershed, that is, the figures of the U. S. Weather Bureau for Berkeley and Oakland, corrected for difference in elevation.

Relation of Rainfall and Runoff.

There is no great essential difference between the two watersheds in the factors that affect runoff, so the same assumptions have been used as for the San Pablo Creek watershed.

Estimate of Runoff.

A curve is shown on diagram No. 9 for the calculated runoff past the site of the proposed dam. The figures used for making up this curve are corrected for evaporation from the average surface of the proposed reservoir so that the quantities shown are the net amounts of water available from storage after losses are deducted.

The slope of the mass diagram approximates the slope of a line representing a draft of between 3 and 4 million gallons per day.

Required Storage.

This is determined as in the preceeding case by finding the maximum vertical intercept between the mass diagram and a draft line starting from a peak of the curve. This indicates an economical storage capacity of at least 1500 million gallons, and probably of 2000 million gallons.

Table No. 35—Estimated Rainfall and Runoff of Pinole Watershed Above Dam Site—Area of Watershed 6,930 Acres.

Season.	Seasonal Rainfall.	Rainfall Corrected for Elev.	Computed Runoff in Inches.	Computed Runoff m. g.	Computed Impounded m. g.	Mass Quant'y m. g.
1874-75....	21.57	25.48	6.49	1,220	895	895
1875-76....	28.56	32.47	10.54	1,980	1,655	2,550
1876-77....	12.33	16.24	2.64	495	170	2,720
1877-78....	32.33	36.24	13.13	2,470	2,145	4,865
1878-79....	23.47	27.38	7.50	1,410	1,085	5,950
1879-80....	23.84	27.75	7.70	1,450	1,125	7,075
1880-81....	31.76	35.67	12.72	2,390	2,065	9,140
1881-82....	18.13	22.04	4.86	915	590	9,730
1882-83....	17.22	21.13	4.46	840	515	10,245
1883-84....	31.10	35.01	12.26	2,310	1,985	12,230
1884-85....	17.95	21.86	4.78	900	575	12,805
1885-86....	32.21	36.12	13.05	2,450	2,125	14,930
1886-87....	18.55	22.46	5.04	950	625	15,555
1887-88....	17.49	19.41	3.77	710	385	15,940
1888-89....	18.29	20.21	4.09	770	445	16,385
1889-90....	46.00	47.92	22.95	4,320	3,995	20,380
1890-91....	23.96	25.88	6.70	1,260	935	21,315
1891-92....	23.38	25.30	6.40	1,205	880	22,195
1892-93....	29.91	31.83	10.15	1,910	1,585	23,780

Table No. 35 (continued).

Season	Seasonal Rainfall.	Rainfall Corrected for Elev.	Computed Runoff in Inches.	Computed Runoff m. g.	Computed Impounded m. g.	Mass Quant'y m. g.
1893-94....	26.65	28.57	8.15	1,533	1,208	24,988
1894-95....	39.01	40.93	16.76	3,150	2,825	27,813
1895-96....	27.72	29.64	8.80	1,660	1,335	29,148
1896-97....	28.94	30.86	9.53	1,794	1,469	30,617
1897-98....	14.40	16.32	2.66	501	176	30,793
1898-99....	27.66	29.58	8.74	1,643	1,318	32,111
1899-00....	25.34	27.26	7.43	1,400	1,075	33,186
1900-01....	25.11	27.03	7.31	1,376	1,051	34,237
1901-02....	25.86	27.78	7.70	1,450	1,125	35,362
1902-03....	25.41	27.33	7.48	1,410	1,085	36,447
1903-04....	33.59	35.51	12.60	2,370	2,045	38,492
1904-05....	29.35	31.27	9.78	1,840	1,515	40,007
1905-06....	27.75	29.67	8.80	1,660	1,335	41,342
1906-07....	31.87	33.79	11.50	2,160	1,835	43,177
1907-08....	19.16	21.08	4.45	837	512	43,689
1908-09....	31.55	33.47	11.20	2,110	1,785	45,474
1909-10....	22.28	24.20	5.85	1,110	785	46,259
1910-11....	30.41	32.33	10.46	1,970	1,645	47,904
1911-12....	14.73	16.65	2.78	523	200	48,104
1912-13....	15.63	16.92	2.87	540	215	48,319
		27.96	8.31	1,563	1,239	

NOTE—Corrections for rainfall in 0.7-in. per 100 ft. elev. Runoff by empirical formula. Evaporation taken as 54 in. per annum over water surface. Records from 1874-1886 taken from the Oakland station and from 1887-1913 are taken from the Berkeley station of the United States Weather Bureau.

STORAGE RESERVOIR.

Location.

The location of the proposed Pinole reservoir as shown on Plates Nos. 1 and 7, lies close to the boundary of the Water District; only a small portion being included within the District. It is about 3 miles slightly east of north from the San Pablo reservoir, and about 5¼ miles up Pinole Creek from the shore of San Pablo Bay. The dam site at the lower end of the reservoir is about 5 miles northeast of the intersection of Macdonald and San Pablo Avenues in Richmond.

Surface Area.

The proposed reservoir with flow line at elevation 260 has a superficial area of about 275 acres.

Capacity.

The capacity of the proposed reservoir as well as the superficial area at various elevations is shown by diagram and table on the accompanying Plate No. 7.

For reasons explained later in this chapter, it is desirable to place the water levels in Pinole and San Pablo reservoirs at the same elevations, but for the present analysis we will consider Pinole watershed and reservoir alone. The required storage of 2900 million gallons is obtained with the water at elevation 260.

PROPOSED DAM.

The proposed dam is located near a small fork of the creek, at a narrow point in the valley about ¾ of a mile below the junction of the county roads to Martinez and about 2¼ miles slightly east of north from the proposed San Pablo dam.

Height.

The top of the dam should be about 10 feet above the maximum high water level, say at elevation 270. The lowest point in the ravine at the dam site is at about elevation 145, hence the maximum height of the dam above the original ground surface would be about 125 feet.

Length.

The length on the crest of the dam at elevation 270 would be about 850 feet.

Volume.

The volume of the earth dam proposed would be somewhat in excess of 500,000 cubic yards.

Construction.

The design and construction of this dam would be of the same general character as that described in detail for the San Pablo dam. Less data is available regarding the foundation conditions. It is ssumed that they will be similar to those at the site of the San Pablo dam. Cross sections and structural details will also be similar.

Spillway.

The spillway will be of the same general type as described for the San Pablo reservoir, but will be smaller in cross section and capacity in proportion to the relative size of the two watersheds.

TUNNEL CONNECTING SAN PABLO AND PINOLE RESERVOIRS.

Advantage of Connecting Tunnel.

In order to make the San Pablo and Pinole Reservoirs act as a unit, it has been proposed to maintain their water lines at the same level by a connecting tunnel and pipe line driven through the intervening hills for a distance of about two miles. The tunnel would be below the high water line of both reservoirs and would normally be under a small pressure. All of the water stored above it would be available by gravity flow from either reservoir and that below the tunnel in one reservoir could be drawn from the other by resort to pumping.

To determine the effect of such an arrangement, a study has been made of the two watersheds considered as one with reservoir storage of the combined capacity of the two.

On Diagram No. 9 is shown a mass diagram of the combined runoff from the San Pablo and Pinole watersheds. It will be seen that the general slope approximates that of a line repersenting a draft of about 15 million gallons per day. Using this draft, and starting with the peak at 1897, the water in the reservoirs remains below high water line for about 7 years, or until 1904. The minimum storage required during this time

is 5000 million gallons, and if we had only this amount, the curve shows that the reservoirs would have been empty or nearly so for some time around 1901.

A more critical period occurred in the series of dry seasons from 1886 to 1890, which is the same period used in the previous discussion to determine the required storage of the San Pablo Reservoir.

Starting with the reservoirs full in the spring of 1886 and drawing on them at a rate of 15 million gallons per day, they would not be full again until about 1890. The maximum vertical distance between the draft line and the mass curve occurs in the summer of 1889, after a very dry season. This shows a required minimum storage of about 8,000 million gallons. If the requirement of the 300 days' supply be added to this, the required combined capacity of the two reservoirs acting as a unit is about 12,500 million gallons.

Required Reservoirs and Elevation of Tunnel.

With the water at elevation 280, the capacity of the San Pablo reservoir is about 8625 million gallons, and that of Pinole about 5250 million gallons, making a total capacity of 13,875 million gallons, or about 1,375 million gallons in excess of the amount estimated as necessary to give the required storage. This excess storage can economically be left in the Pinole reservoir below the level of the connecting tunnel which, as determined by this method, should be at about elevation 240.

If the tunnel were placed at elevation 240, the combined storage capacity which would be available by gravity flow at the San Pablo filters would be all of the Pinole reservoir that lay above the tunnel and the entire capacity of San Pablo reservoir.

Length.

The connection between the Pinole and San Pablo reservoirs would be obtained by a pressure tunnel driven on the shortest possible alignment with a pressure pipe leading from the lower portal in the San Pablo valley, upstream to the San Pablo dam.

The length of the tunnel section of the connecting conduit would be about 5600 feet, and the pipe line section would be a little shorter, the total length about two miles.

Location.

The Pinole end of the tunnel should head in the arm of the reservoir extending south, about ¾ of a mile east of the dam. The general direction should be southwest or at right angles to the direction of the main ridge separating the two watersheds. The San Pablo portal would be on the side hill above the creek opposite a point about ¾ of a mile downstream from the San Pablo dam. From this point a pipe would be laid approximately on a contour, entering the reservoir either through the dam or through a short tunnel around the end of the dam.

Capacity.

The smallest tunnel section it is practicable to drive would be of sufficient capacity to conduct the water. This would probably have a horseshoe shape, cross section about 5½x6½ feet. The pipe line portion

will be made of sufficient capacity to carry a flow of 6 million gallons per day with a maximum loss of head of 10 feet. For a pipe line 4,000 feet long, this will be about 24 inches in diameter.

CONDUIT TO RICHMOND.

For the conduit from the San Pablo Reservoir to the distributing system two alternate routes have been considered. One follows in a general way down the creek and enters the distribution system from the north. This line is about six miles long.

The other route comes through a tunnel direct from the San Pablo dam to a portal on the side hill about half a mile directly up the hill east of the intersection of San Pablo and Macdonald Avenues. From the portal a pressure main is carried down to San Pablo and Nevin Avenues at which point the water enters the distribution system. The latter route is the more direct and by far the more desirable. The loss of head through the tunnel is negligible, even for the ultimate proposed draft of 12,000,000 gallons per day. The pipe line from the tunnel portal to San Pablo and Nevin Avenues is short and can be made of 30-inch pipe and the loss of head through it will still be within permissible limits. Moreover a concrete lined pressure tunnel, built through solid rock as this one is proposed to be, will be as permanent a form of construction as it is possible for human agency to build.

If the six-mile conduit down the creek were used it should be 36-inch or preferably 42-inch pipe in order to avoid excessive friction loss.

If built of cast iron, its cost would be fully twice the cost of the tunnel conduit, if built of wood stave or riveted steel pipe, its cost would not be much different from that of the other route.

The chief advantage of the tunnel route over the pipe line are much smaller friction losses, much more permanent construction, and the possibility of a largely increased capacity with nominal loss of head without any increase in size. Another advantage and one more remote is the possibility of collecting water from Wild Cat Creek under which the conduit passes.

Tunnel.

The tunnel as proposed will head just below the San Pablo dam in a small branch canyon running out to the west. It will be a pressure tunnel built through rock and with a thin concrete lining reinforced to withstand the earth pressure from without and about 100 feet head of water from within. The cross section will be as small as it is practicable to build and as suggested for the San Pablo-Pinole tunnel would probably be a horseshoe shape $5\frac{1}{2}$x$6\frac{1}{2}$ feet. The total length as scaled from the best maps available would be about 15,500 feet, and the loss of head through the tunnel with a draft of 15,000,000 gallons per day is less than 1 foot. For the same draft through the six-mile line down the creek route, the loss of head would be about 45 feet for a 36-inch pipe and about 21 feet for a 42-inch pipe.

Wild Cat Creek Diversion.

The tunnel will pass under Wild Cat Creek at an elevation of about 75 feet below the creek bed. It is proposed to sink a shaft in the vicinity of Wild Cat Creek which will be used during construction to facilitate the work of driving the tunnel. After construction the shaft may be lined and used to divert water to the San Pablo reservoir from Wild Cat Creek during the rainy season. If this were done, however, it would necessitate a change in location of the filters, which to treat the water from Wild Cat would then have to be placed at the west portal of the tunnel.

CHAPTER No. VII.

Filtered Water Supply from Sacramento or San Joaquin Rivers

GENERAL FEATURES OF PROJECT.

The principal features of a water supply for the Richmond Water District from the Sacramento or San Joaquin Rivers are filtration and pumping. As the supply would be taken from the lower reaches of one of the two rivers, the engineering features are the same for either the Sacramento or San Joaquin, and hence the greater part of the required plant is common to the two, and the whole matter should be studied as one problem.

The plant will be designed to meet the requirements for capacity given on pages 134 to 137 of Chapter No. VIII. The average daily consumption for which provision is made is 12,000,000 gallons. Sufficient storage available by gravity will be provided at the immediate head of the distribution system to equalize all but the monthly variations. As it is estimated that the maximum average draft for an entire month may be 125 per cent. of the average, or 15,000,000 gallons per day, the proposed conduit will in general be designed for this ultimate capacity. In order to insure this, certain critical portions will have still further reserve capacity beyond this amount. To conserve present expenditures, it will be possible to construct portions of the plant with the smaller capacity equivalent to the probable immediate demand, and possibly for the present to omit certain other portions altogether. This will hardly apply, however, to the pipe line which represents the bulk of the cost of the proposed conduit. As it is obviously incapable of enlargement, it must be at once constructed of size sufficient for the ultimate demand. The pumping plants and filters, however, can be constructed in units so that the first installations will correspond with the immediate demand, and so designed that they are capable of convenient enlargement by the addition of similar units as the demand increases. The storage reservoirs can be constructed with low dams, and have their capacity subsequently enlarged by raising the dams as required. It is estimated that the demand will soon be for an average of six million gallons per day, requiring delivery through the conduit at the rate of 7,500,000 gallons per day during the maximum months. The filters should have additional reserve capacity, as units may frequently be required to be put temporarily out of service for cleaning or repair. They will hence be designed for an immediate capacity of 9,000,000 gallons per day, and an ultimate capacity of twice this amount. The pumping plants should also have additional reserve capacity in case one of the units is temporarily disabled. They will be designed for an immediate capacity of 15,000,000 gallons per day ultimately enlargeable to 22½ million gallons per day.

Position of Intake.

In a general way the further downstream the intake can be placed, the cheaper will be the conduit. The controlling condition is the presence of salt water, and the distance that it goes up stream.

Sugar Refineries' Experience.

The Sugar Refinery at Crockett takes water for sugar refining from the river. Sometiems, at very high water, it is possible to take water at the refinery. Otherwise a tank steamer goes up stream to a point where the water is sufficiently fresh. It is frequently necessary to go thirty miles, and at times nearly forty miles, or to a point on the San Joaquin River four miles above Three Mile Slough. The analyses of water actually used at the refinery indicate that water is frequently used with a greater degree of salinity than would be acceptable for a public water supply.

The records of the distances above Crockett at which water was taken for the last seven years are shown on the accompanying diagram No. 11. In general, the Sugar Company usually takes water from the San Joaquin River as soon as a point has been reached at which the chlorine content is less than fifty parts per million.

An analysis of these records, which are available for the last six years, shows that it has not been necessary to go more than thirty miles above Crockett (five miles above Antioch) on an average of more than nine days per year, varying from three days per year in 1909 and 1912 to thirty-two days per year in 1910. Since the San Joaquin River has a much larger channel in the neighborhood of Antioch than the Sacramento and also a smaller summer flow, brackish water exists further upstream than in the Sacramento River. The analyses given in this report show that the chlorine content at Toland's Landing on the Sacramento River is slightly better than at False River on the San Joaquin, the latter being about 9 miles above Antioch, and thirty-four miles from the Sugar Refinery. The Sugar Company's records show that they went farther than this only six times in six years. It is probable that even during these times it would have been possible to get fresh water farther downstream, except at high tide.

Intake at Antioch.

Antioch, twenty-five miles above the refinery, and very nearly opposite the mouth of the San Joaquin River, gets its water supply directly from the river without treatment, and it is said to be generally satisfactory. In dry seasons like the present, however, water pumped at low tide may become distinctly brackish, as shown by the analysis given hereinafter. In many years' use of this water, however, at Antioch, there appears to have been very little objection raised on this account.

Bacterial analyses show much more evidence of sewage pollution at Antioch than at points a few miles farther up the river. That the quality of the water is sometimes unsatisfactory is evidenced by the fact that the town is now putting in filters. These, however, will not relieve the objectionably large salinity of the water at high tide during extreme low stages of the river.

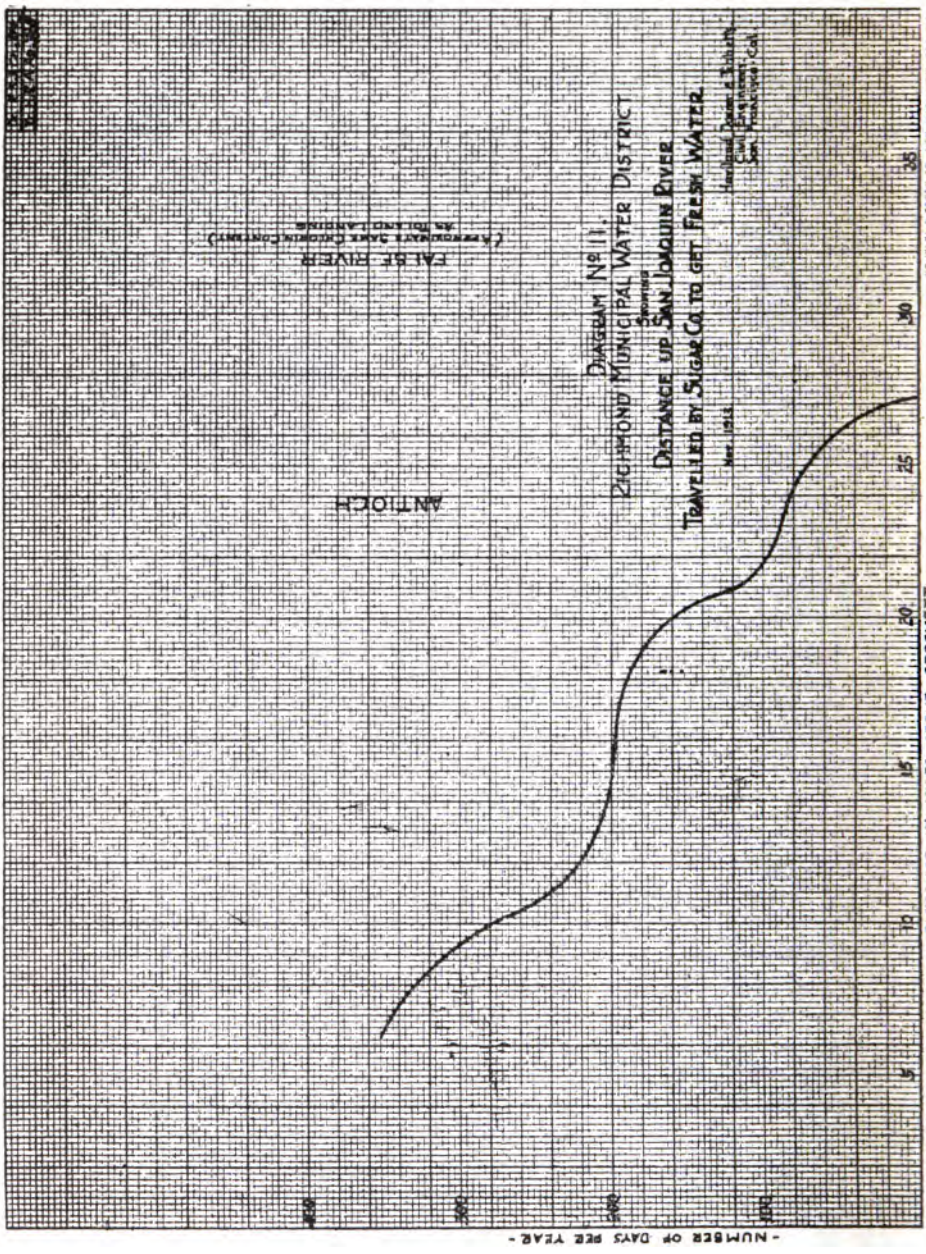


DIAGRAM Nº II.
RICHMOND MUNICIPAL WATER DISTRICT
Showing
DISTANCE UP SAN JOAQUIN RIVER
TRAVELLED BY SLOAN CO. TO GET FRESH WATER
ANTIOCH
FALSE RIVER
DISTANCE IN MILES ABOVE CROCKETT.
NUMBER OF DAYS PER YEAR

Chlorine Determinations in Lower Rivers.

The present season has been an exceptionally dry one, the Sacramento River reaching the lowest stage recorded for many years, so that excellent opportunity is afforded at the present time for a determination of the extreme condition regarding the presence of salt water in the lower reaches of the river. A large number of analyses to determine the chlorine content in the water, were made around Sherman Island, covering the lower reaches of both the Sacramento and San Joaquin Rivers, as far up as Three Mile Slough. In general, these analyses were made of surface waters in the rivers, but a few experiments were made by taking samples at different depths to determine the variation in the chlorine content with the distance from the surface. This indicated no important difference except for a short time at extreme high tide at the farthest point upstream affected by tidal conditions. In these instances it was found that the fresh water, being slightly less dense, had a tendency to flow out over the top of the salt water, so that the freshest water was found at the surface. For a distance of two miles below Three Mile Slough there is no trace of salt water in either the Sacramento or San Joaquin Rivers. The normal chlorine content thus obtained for the Sacramento River was about ten parts per million, and for the San Joaquin River about twenty parts per million. To be acceptable for municipal supply, water should certainly not contain more than 100 parts per million of chlorine, and preferably not more than fifty parts of chlorine. The water at Antioch at all times was found to contain three to five times this upper limit. It should be remembered, however, that present low water conditions are extreme, and that the upper limit of salt water is farther down stream the greater the flow in the rivers. Throughout the most of this season the effect of salt water has not extended as far upstream as at present, and the majority of seasons are much more favorable than this one.

The results of the chlorine determinations in the lower Sacramento and San Joaquin Rivers, together with the variation in chlorine content with the tidal range are shown graphically on the accompanying diagram No. 12. The diagram shows that the chlorine content tends to increase on a rising tide. The peaks of the chlorine curves lag somewhat behind those of the tidal range. Continuous hourly observations were taken at four points, Antioch, Dutch Slough and False River on the San Joaquin and Baker's Point, opposite Toland's Landing on the Sacramento. The latter point shows the smallest chlorine content. The content at Antioch is over ten times that of any of the other points. For comparative purposes, the diagram shows the average chlorine content in water supplies now in use for Richmond and other cities of the San Francisco region.

Selection of Toland's Landing.

As a result of the preliminary investigations, it was tentatively determined that if the San Joaquin River were used, the mouth of False River would be far enough upstream for the intake, and if the Sacramento River were used, Toland's Landing would be the proper point. Under the present extreme low water conditions, the average chlorine content at the mouth of False River was 26.2 parts per million, or only one-thirteenth of the chlorine content at Antioch near the mouth of the

river. At Toland's Landing on the Sacramento, the average chlorine content was found to be 21.1 parts per million. Analysis of well waters at Richmond shows 30 to 60 parts per million, with one group of wells in constant use, going over 500 parts per million. It is probable that at either of the locations suggested for the intake tide water would have no effect whatever during the greater part of an average season.

The Sacramento River water is, in general, of much better quality than the San Joaquin water, and its future quality less liable to deteriorate. Toland's Landing is 7 miles from Antioch, and False River 9 miles, so that the total length of the conduit, if started at Toland's Landing would be 2 miles less than if started at False River. If the intake were located near the mouth of False River, the pipe would have to cross Dutch Slough. If the water is obtained at Baker's Point or any other location on the Sacramento River, the pipe line would have a submarine crossing of the San Joaquin River. If located at Toland's Landing or any other point on the right bank of the Sacramento River there would be an additional submarine crossing of the Sacramento. River or of the straits below.

The site at Toland's Landing has certain physical advantages over any other, as it is the one point on the lower Sacramento or San Joaquin rivers, except Antioch and Rio Vista, where solid foundations can be obtained. This is an important matter for the expensive pumping plant required. If the plant were located on any of the islands, it must be founded on peat of an indeterminate depth, subject to settlement under the constant vibration of heavy machinery, and probable destruction in the case of earthquake or of levee failures in the immediate vicinity during floods. The pyhsical advantages of securing firm foundations for the pumping plant above the danger from flood water outweigh the disadvantages of the submarine crossings of the Sacramento and San Joaquin Rivers.

The Toland's Landing site will hence be adopted because it is desirable to secure water from the Sacramento River, because Toland's Landing is the lowest point from which it will be safe to take water, and because Toland's Landing is the best location of any point on the lower Sacramento River except the vicinity of Rio Vista.

Effect of Flood Control Work.

The Government flood control work in widening out the mouth of the river, as shown on the accompanying map, Plate 8, will cut off Baker's Point, receding the south bank of the river opposite Toland's Landing until it is about 3000 feet wide, instead of 700 feet wide as at present. This work, which will be soon accomplished, will make the submarine crossing of the Sacramento River much longer than it is now. It will also make the lower end of the river much larger. It is not believed, however, this will have any very great effect on the quality of the water in the lower river as the dry weather flow is too great. This work will probably emphasize the relative advantages of the Toland's Landing site as the low water channel will remain as at present, while the opposite side of the river after enlargement may tend to shoal extensively. Navigation requirements will probably keep the low water channel adjacent to Toland's Landing because of its importance as a shipping point.

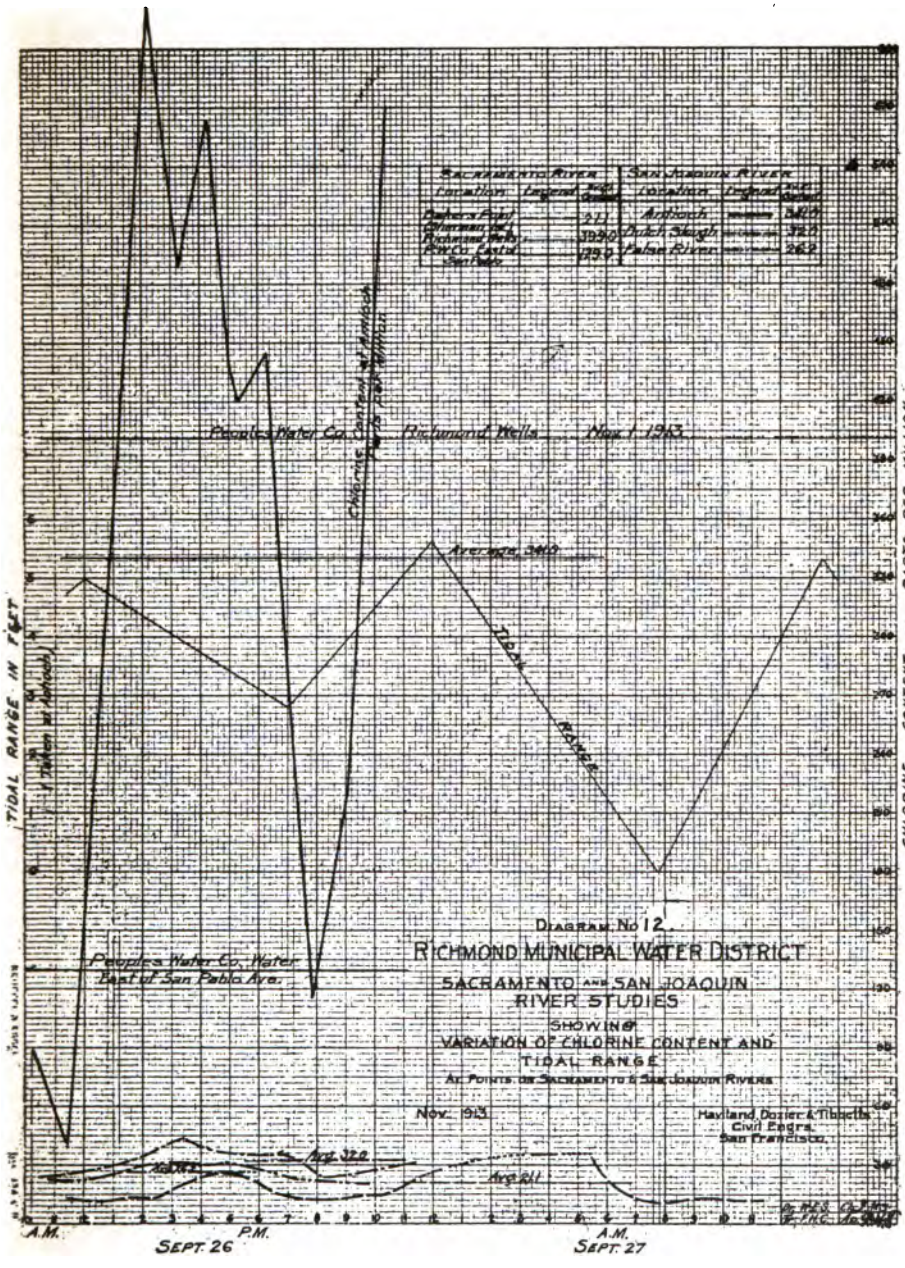


DIAGRAM No 12.

RICHMOND MUNICIPAL WATER DISTRICT

SACRAMENTO AND SAN JOAQUIN RIVER STUDIES

SHOWING VARIATION OF CHLORINE CONTENT AND TIDAL RANGE

AT POINTS ON SACRAMENTO & SAN JOAQUIN RIVERS

Nov. 1913

Hayland, Dozier & Tibbetts
Civil Engrs.
San Francisco.

QUALITY OF WATER AS INVESTIGATED BY SAN FRANCISCO.

Allen Hazen's report to the City of San Francisco contains the following statement:

"Sacramento River water is clearly of better quality than San Joaquin water. This is well shown by plottings Nos. 49 and 50, made of results deduced from analyses made by the U. S. Geological Survey, contained in Water Supply, page 237. These results show the Sacramento River to be not only much softer and more free from mineral matter, but the seasonal variation is much less. In the early summer the difference is not so great, but in the late summer and the autumn the San Joaquin River water at Lathrop becomes highly mineralized, and for that reason not well adapted to public water supply. The San Joaquin River water further has a yellow color, while the Sacramento River water is substantially free from color. Both of the waters are somewhat turbid, and this turbidity seems to persist at all seasons of the year, although in varying amounts. The navigation in the rivers and the ebb and flow of the tide tend to keep fine clay particles permanently in suspension.

"Both the Sacramento and San Joaquin waters are subject to sewage pollution by the towns upon their banks. The largest city upon the Sacramento is Sacramento, and the largest upon the San Joaquin, Stockton.

Treatment of River Waters.

"The waters of both rivers in their raw state are not suitbale for public water supply. They can be filtered so as to greatly improve their quality. The Sacramento River water may be filtered so as to produce a good potable water at all seasons of the year, removing the turbidity, color, and the results of sewage pollution. The San Joaquin River could be similarly purified, but would contain an excess of mineral matter during part of the year. A part of this could be removed at greatly increased expense by softening, while other parts could not be so removed.

"The best way to treat the water is by means of mechanical filtration. The raw water will first be treated with a coagulent, and allowed to stand in coagulating or settling basin for some hours, during which the operation of coagulation will take place and the heaviest part of the matters resulting from it will settle to the bottom of the basin, from which they will be flushed back into the river at intervals.

"The water will then pass to sand filters operating at a rather high rate and cleaned mechanically by a reverse current of filtered water. After leaving the filters, if thought necessary or desirable, the water may be finally treated with hypocholorite of lime.

"Sacramento River water filtered and purified in this way would be somewhat softer and would have on the whole probably a more attractive physical appearance than the water now supplied in San Francisco, which is delivered after storage in open distributing reservoirs.

"If the San Joaquin River water were taken the average hardness would be as great or greater than that of the present supply and during a part of the year it would be much greater.

	Hardness as parts per mil., calcium carbonate.
On the best available information the average hardness of the water now supplied in San Francisco is in the neighborhood of	100
San Joaquin River water, analyses of 1906-08, about ..... (This is sure to increase with irrigation.)	90
Sacramento River water, about	55

"It is possible to make a roughly approximate financial estimate of the value of hardness in a public water supply. An allowance of ten cents for each part per million in one million gallons has been assumed to be an average figure. On this basis a difference of 80 parts per million in total hardness is worth $8.00 per million gallons."

Possible Future Changes in Quality.

The possibility of material future changes in the quality of the Sacramento and San Joaquin River waters, especially during low stages of the rivers is discussed in the Report of the Advisory Board of Army

Engineers, dated Feb. 19, 1913, "On Investigations Relative to Source of Water Supply for San Francisco and Bay Communities." The minimum discharge of the lower Sacramento River is given as about 6,000 cubic feet per second. The War Department regulations permit diversion in the upper river only when the stage is 2 feet or more above low water. It is believed that the low water flow in the future may be increased by mountain reservoirs constructed for irrigation or power development. The increasing use of water for irrigation in the Sacramento Valley will also tend to equalize the flow, the low water flow being increased by seepage or return waters, from the irrigated lands. Such seepage waters, however, tend to carry into the river, dissolved mineral matter leached from the soil, and thus to increase the hardness of the water, especially during low stages.

The minimum flow of the San Joaquin River is given as only 230 cubic feet per second or less than one-twentieth the minimum flow of the Sacramento.

The discussion concludes with the statement,

"that with power development, irrigation and navigation interests, all dependent on a well maintained low water flow of the streams, and considering also that a considerable percentage of water used for irrigation seeps back into the streams, it does not seem likely that the flow of the Sacramento River need be so lowered as to permit sea water to get materially farther up the river than at present."

Also,

"any scheme for supplying filtered water from the San Joaquin River would have to depend on the inflow to the lower reaches of that river of Sacramento River water."

Possibility of Sewage Pollution.

The possibility of sewage pollution is discussed in much detail in Prof. Hyde's report on a "Filtered Water Supply for the City of Sacramento," in which the conclusion is reached that, due to the comparative sparcity of the population over the watershed, the river would never become seriously contaminated, especially in view of the fact that the sanitary regulation of streams is enforcible by the State Board of Health, under the drastic provisions of broad legal powers.

Prof. Hyde estimated that in 1900 the total resident population within the drainage basin of the Sacramento River was approximately 151,000 persons, or 6.4 persons per square mile. By 1950 he estimates that this would have doubled. He further states as follows:

"CAPACITY OF RIVER TO RECEIVE SEWAGE. Well studied experience has shown that a river of the character of the Sacramento and having the same minimum rate of discharge, should be capable of receiving the crude sewage flow of very nearly 2,000,000 persons, as a sort of minimum figure, without causing a nuisance; i. e., without losing its dissolved oxygen content and becoming a sort of elongated cesspool or septic tank, rather than a stream having a distinct oxidizing power and capable of more or less complete self regeneration. This is true because of the remarkable power of self-purification which a stream of this type and condition possesses. To just what extent the contamination with crude sewage may be carried and yet permit the quality of the water to be such as to be readily redeemable by reasonable modern processes of purification is not wholly apparent, but experience in other places shows that that extent may be very considerable, and may be fully one-half of the figure given above for the limiting conditions of a nuisance.

"FUTURE CONSERVATION OF PURITY. Public opinion with regard to the essential importance of the conservation of the purity of waters in inland streams is rapidly becoming crystallized and there are already in force in certain

states of the United States laws, which are beginning to effectively control the degree of pollution of such waters. Indeed the laws of California are sweepingly severe in this matter, and although perhaps incapable of enforcement to the letter at the present time, they represent a tendency which is most significant. The situation is therefore thoroughly reassuring from the standpoint of indefinite future use of surface waters, after suitable purification, for the supply of cities and towns, such as Sacramento, located on streams which happen to form their most logical source of supply.

"CONCLUSIONS WITH RESPECT TO FUTURE CONTAMINATION. Reviewing the facts and conditions above outlined, the most obvious and definite conclusion must be that the Sacramento River will not be contaminated with sewage to such a degree that it will not be satisfactory as a source of supply (i. e., not readily redeemable by modern filtration processes) for so many years in the future, if indeed ever, that no apprehension on this score need be felt, and further consideration of this question herein would seem to be wholly unnecessary."

Chemical Analyses of Water Samples.

Complete chemical analyses were made of water samples obtained from the San Joaquin River at Antioch, at the mouth of Dutch Slough, and at the mouth of False River on September 20, 1913. Also of samples obtained from the Sacramento River at Toland's Landing on September 20th, and November 1, 1913.

Table No. 37—Chemical Analysis—Sacramento and San Joaquin River Waters.

Impurity.	San Joaquin River at Antioch	San Joaquin River at Dutch Slough	San Joaquin River at False River	Sacramento River at Toland's Landing.	
	9-20-13	9-20-13	9-20-13	9-20-13	11-1-13
$SiO_2 + Al_2O_3 + Fe_2O_3$	12.4	12.8	13.2	15.0	19.2
Ca	44.2	20.8	19.0	18.7	16.0
Mg	84.0	60.0	7.5	7.2	7.8
Na	640.	60.0	19.3	13.7	14.0
Cl	1123.	57.0	19.6	9.2	12.8
CO_3 equivalent to HCO_3	50.1	49.2	50.0	50.1	46.6
SO_4	166.0	14.4	8.7	7.8	6.4
	2119.7	224.3	137.3	121.7	122.8
HCO_3 (the way the carbonic acid exists)	101.8	100.0	101.5	101.8	94.7
Temporary hardness as $CaCO_3$.	83.4	82.0	83.2	83.4	77.5
Total hardness as $CaCO_3$					
from calcium	110.	57.	47.5	46.	40.0
from magnesium	345.	41.	31.	30.	32.0
Total	455	98	78.5	76.	72.0

The chemical analyses were made by Mr. S. A. Tibbetts, Chemist.

No extended discussions will be given of these analytical determinations as the significance of each is extremely technical. The most important is the total hardness, and in this respect the Sacramento River at Toland's Landing is the best of any. In all other respects the Sacramento River water is shown to be of a quality which could be made thoroughly satisfactory by filtration.

Turbidity and Micro-organisms.

The physical and chemical character of the water, especially its turbidity, influences the design of purification works, more than the bacterial content.

In waters which are constantly turbid, like those of the Sacramento River, growths of algae and similar micro-organisms are not excessive because of the absence of sunlight at moderate depths of the river. The constant movement of the water also is an unfavorable condition for their growths.

The chief source of supply of such organisms in the river at Toland's Landing would probably come from the drainage of the flood basins of the Sacramento River. This source of supply will be gradually eliminated by the extension of flood control works in the upper valley.

The United States Geological Survey made a series of observations during the year 1904 on the turbidity of the water in the Sacramento River at Sacramento. The readings were taken with a turbidity rod, graduated to indicate how far beneath the surface of the water a platinum wire one millimeter in diameter could be observed. The readings obtained in this way can be used by comparison with silica standards.

The results obtained are shown by the following table:

Table No. 38—Daily Turbidity Readings—Sacramento River, at Sacramento, Cal., During the Year 1904.

(Readings expressed in parts per million referred to the silica standard.)

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	...	85	250	200	95	75	60	40	50	90	70	150
2	...	100	250	150	90	85	65	45	45	80	100	150
3	...	85	300	150	90	75	70	35	50	65	60	180
4	...	110	300	120	80	90	65	40	55	85	75	140
5	...	150	200	130	80	85	75	35	55	65	55	110
6	...	400	250	130	95	75	75	30	60	75	60	80
7	...	180	200	200	110	85	70	45	55	65	75	65
8	...	180	150	200	100	80	70	40	50	65	70	65
9	...	100	150	200	110	80	65	40	45	150	65	45
10	160	110	300	180	110	75	60	50	50	250	70	75
11	170	75	300	160	120	75	55	45	50	200	70	75
12	180	350	300	100	100	80	55	55	50	400	65	75
13	250	600	250	100	100	75	55	40	50	200	70	55
14	90	400	200	110	100	75	55	55	55	200	75	60
15	100	160	250	100	100	75	55	65	50	140	75	70
16	100	700	250	110	90	70	60	65	40	110	50	100
17	100	400	150	120	90	70	50	50	45	90	180	110
18	110	250	300	130	90	75	50	65	45	85	100	90
19	200	180	250	100	100	70	40	60	40	200	65	80
20	130	160	300	130	110	70	40	60	40	140	60	80
21	110	300	250	130	110	75	50	60	40	90	65	60
22	120	800	250	100	100	60	40	60	40	55	70	60
23	100	1000	250	95	100	65	45	65	55	60	120	80
24	100	800†	200	95	90	65	45	60	85	60	100	100
25	100	600	180	100	85	60	40	50	150	60	80	80
26	100	500	150	100	100	60	45	55	150	60	70	200
27	100	450	250	110	95	60	45	55	250	55	75	160
28	100	350	200	100	95	60	50	55	100	60	80	200
29	100	250	300	100	90	65	40	60	160	55	110	110
30	95	...	250	90	85	65	40	60	140	60	110	200
31	90	...	250	...	85	...	40	50	...	60	...	...
Av.	*120	340	240	130	100	75	55	50	70	110	80	‡110

* For 22 days. † Estimated. ‡ For 30 days.

Average for year, 122 p. p. m.

NOTE—The readings were taken with a turbidity rod at the foot of K Street, at east bank of stream, off of wharf.

The observations were made by I. C. Pierson, under direction of the U. S. Geological Survey.

Bacterial Analyses.

Bacterial analyses were made of two samples taken on September 27, 1913, from the San Joaquin River, one at Antioch and one at the mouth of False River, and two samples taken the same date from the Sacramento River, one at the mouth of Three Mile Slough and one at Toland's Landing.

The results of the analyses as made by Prof. Gay of the Department of Pathology of the University of California are shown in the following table:

Table No. 39—Bacterial Analyses of Water Samples.

Sample No.	Date Taken.	Time Taken.	Point Where Sample Was Taken.	Bacteria Per Cu. Centimeter.	B. Coli Indicating Sewage Pollution.
1	9/27/13	A.M. 11:30	San Joaquin River at mouth of False River.	15,000	Present in every 1 c.c.
2	9/27/13	M. 12:00	Sacramento River at mouth of Three-mile Slough	9,500	Present in every 1 c.c.
3	9/27/13	P. M. 1:55	Sacramento River at Toland's Landing	14,500	Present in every 1 c.c.
4	9/27/13	3:30	San Joaquin River opposite Antioch W.W.	53,000	Present in every 0.1 c.c. indicating marked sewage pollution.

The Sacramento River appears to have less sewage pollution than the San Joaquin. The amount is small except possibly at Antioch. All the samples could readily be made perfectly safe for drinking purposes by filtration and possibly sterlization.

DESIGN OF MAIN CONDUIT.

Pipe Line.

The main conduit from the intake on the Sacramento River to the distribution system in Richmond will be about 45 miles in length. Its cost will be about one-half the total cost of the entire project. It is obviously incapable of enlargement, except by the construction of additional lines, and hence its design should be carefully studied with reference to materials, method of construction, and especially economical sizes for both its present and future draught.

Character of Construction of Pipe Line—Wood Stave Pipe.

Wood has been used in the form of bored pipes for over 100 years. The first wood stave pipe built in accordance with modern construction was made in Denver, in 1883. Since then many large pipe lines have been designed with diameters up to 96 inches, and heads up to 400 feet.

Wood stave pipe is essentially a pipe made of wooden staves of variable length, with radial edges and concentric faces, held together by metal bands, rods or wire, spaced in accordance with the demand of the strains from internal water pressure. There are many varieties differing mostly in the form of staves, and the method of banding the staves together. The most prevalent type is known as the "Colorado Pipe" —the invention of Mr. Allen of Denver. It is built continuously in the trench, with the staves breaking joints. The bands are round, oval or flat steel bars ⅜ to 1 inch in diameter and spaced 2 to 12 inches apart, provided with a head or clevis on one end, and an upset thread on the other.

In another common form, the pipe is machine made, and shipped to the work in sections, 8 to 20 feet long. Joints are made by the introduction of cast iron collars or by making in the wood staves a chamber on one end and tenon on the other.

Another recent type is continuous wire wound wood stave pipe constructed in place, with the staves breaking joints and the pipe wound with wire of any desired size by means of an ingeniously contrived machine, operated by air pressure, which travels around the pipe. Danger from wire breakage may be avoided by stapling the wires and by the use of a multiple wire winding machine which can introduce two or more separate wires.

The special field for wood stave pipe is for moderate pressures and sizes. It has been seldom used for pressures in excess of 100 pounds per square inch, corresponding to about 250 feet of head. Experience seems to show that it should not be used under pressures of less than 50 feet of head, because if used under less pressure, there has sometimes been a tendency toward rapid decay.

The life of wood stave pipe appears to vary with the character of the soil in which it is buried, with the pressure of the water, and other features affecting more particularly the life of the metal bands. The main essential for a long life is to keep the pipe at all times full and under sufficient pressure to insure complete saturation. If the pipe is buried, the back fill should be of clean earth without vegetable or organic matter. Under these conditions the life of wood stave pipe should not be less than 20 years and in many cases is much greater.

The results of recent tests seem to show that especially under conditions of continuous usage the interior of wood stave pipe becomes smoother than that of other kinds of pipe, and hence the carrying capacity for a given size and head is greater than for other kinds of pipe.

As the first cost of wood stave pipe is less than that of any other type, it seems to be well adapted for the proposed conduit. From figures given for estimating purposes, it would seem that the new type of continuous wire-wound pipe may be considerably cheaper than other types. A detailed study has been made of the use, design and probable life of wood stave pipe, and references are given in Appendix No. 8 to literature bearing on the subject, with a list of some recent wooden pipe lines.

Riveted Steel Pipe.

Riveted steel pipe has been widely used in recent years, especially for large sizes, under high heads. It is made of comparatively thin sheets of steel, riveted longitudinally and transversely, with the thickness of plates adapted to the heads for which the pipe is designed.

It is also especially adapted to long lines with few branches. It is cheaper, lighter and more easily handled than any other type of metal pipe. There is less liability of breakage while in service, and the pipe is more reliable than cast iron to resist tensile strains and shocks due to water hammer.

The most important feature of the design and construction of riveted steel pipe is the protective coating intended to prevent corrosion and tuberculation. Unless these coatings are very carefully and thoroughly applied, there will be spots where the protective coating will not remain intact and the pipe will deteriorate rapidly.

The life of the pipe is greatest where it can be buried in dry or sandy soils, and least in wet clay or in soils having appreciable quantities of chlorides. If thoroughly protected, it is probable that 40 years is a fair prediction for the life of riveted steel pipe, though it has hardly been in use long enough to determine this from actual examples. There are many instances which seem to indicate an indefinitely long life; usually, however, in the course of a number of years local corrosion or tuberculation will cause leakage.

As it is impracticable to design a large pipe thick enough to withstand external pressure, if a vacuum is created within, special care must be taken to provide automatic valves at various points along the line, especially at all summits, to allow the entrance of air, in case of breaks in the pipe line.

Because of the projection of rivet heads in the interior section of the pipe, and because of the probability of corrosion and tuberculation with continued use, it is usual to assume a somewhat greater frictional resistance and hence a lesser capacity for riveted steel pipe of a given size and head than for other kinds of pipe.

Appendix No. 9 gives a list of references to articles on riveted steel pipe with some recent important examples.

Cast Iron.

For many years cast iron pipe has been the standard for heavy water works construction. Its manufacture and use are so well known as to need little comment. The thickness is usually so great that it has a life of 80 to 100 years or more under average conditions.

Corrosion takes place slowly but can be largely prevented by the use of protective coating. Cast iron pipe of standard design is perfectly safe, and fairly satisfactory for almost any condition of use, but it is heavy, hard to handle, and much more costly for larger sizes than riveted steel or wood stave pipe.

Concrete Pipe.

Reinforced concrete pipe has been very recently used for some large size pressure siphons, and is in general use for low pressure storm sewers, and similar construction Reinforced concrete pipe with screw

ends has been recently proposed for high pressure water works service. If it can safely resist the strains imposed, and can be made water tight so that leakage will be unimportant, it may furnish a permanent form of construction of less cost than cast iron, or possibly even than of riveted steel.

Economical Size.

The determination of economical sizes for a long conduit carrying a given amount of water involves detailed consideration of the first cost of the pipe line, and the cost of pumping water through the line. The Sacramento conduit for the Richmond Water District is designed to deliver water at the average rate of 12,000,000 gallons per day, with a maximum rate of delivery during the months of maximum use of 15,000,000 gallons per day. The pumping machinery, filters and other accessories will be designed for a present consumption of half of this amount only.

The larger the pipe is built, the greater becomes its first cost, but the less becomes the annual cost of pumping through it a given amount of water. With the maximum draft for which the pipe is designed about half the total head against which the pump must operate is caused by frictional resistance to the forcing of the water through the long pipe line. This frictional resistance varies inversely, approximately as the square of the diameter of the pipe. In order to make the first cost of the pipe line comparable with the cost of pumping, the latter has been capitalized so as to determine a sum, the interest on which would pay the annual cost of pumping. For any particular size of pipe, the total cost to the district is represented by the sum of the first cost of the pipe, plus the capitalized cost of continually pumping through it the amount of water required. The most economical size of pipe is that for which the total of these two items is the least. As the required delivery of the pipe increases during its period of use, the capitalized cost of pumping should be computed on the average delivery during the life of the pipe, if such a figure could be determined with certainty.

Estimates have been made for the main conduit with diameters of 24, 30, 36, 42 and 48 inches with alternate figures for wood stave pipe, riveted steel pipe, and cast iron pipe of each of the sizes given. The estimates are made on the basis of 6,000,000 gallons per day delivery, and of 12,000,000 gallons per day delivery. The diagram No. 13 shows graphically the estimated cost of pipe lines of each size and of each of the three materials. Superimposed on the diagrams representing first cost of the pipes are diagrams representing the capitalized cost of pumping through them 6,000,000 gallons per day, and 12,000,000 gallons per day, the most economical size of pipe for the delivery considered is that for which the total height of the combined diagrams is least. If wood stave pipe were used with the present delivery of 6,000,000 gallons per day, there is little choice between 30, 36 or 42-inch pipe. With an ultimate delivery of 12,000,000 gallons per day, there is no essential difference between 36, 42 and 48-inch pipe. Practically the same comments apply to the use of riveted steel pipe. If cast iron pipe is used, the first cost becomes relatively of much greater importance as compared with the

cost of pumping and hence smaller sizes would be economical. For a draft of 6,000,000 gallons per day, 24-inch or 30-inch could be used, and for 12,000,000 gallons per day, 30, 36 or 42-inch.

For a project of this nature, it is usual to choose a somewhat smaller pipe than the one shown to be the most economical by a theoretical analysis of the character given. This reduces the first cost and transfers the additional cost of pumping to a later date at which time the increased financial resources of the District will make it less of a burden. With this consideration in mind, a 36-inch size is recommended with either wood stave or riveted steel pipe and will be used as a basis for cost estimates.

For a supply of 6,000,000 gallons per day with either riveted steel or wood stave pipe, a 36-inch diameter appears to be slightly more economical than either the 30 or 42-inch.

GENERAL DESCRIPTION OF EACH UNIT OF THE PROPOSED SACRAMENTO CONDUIT.

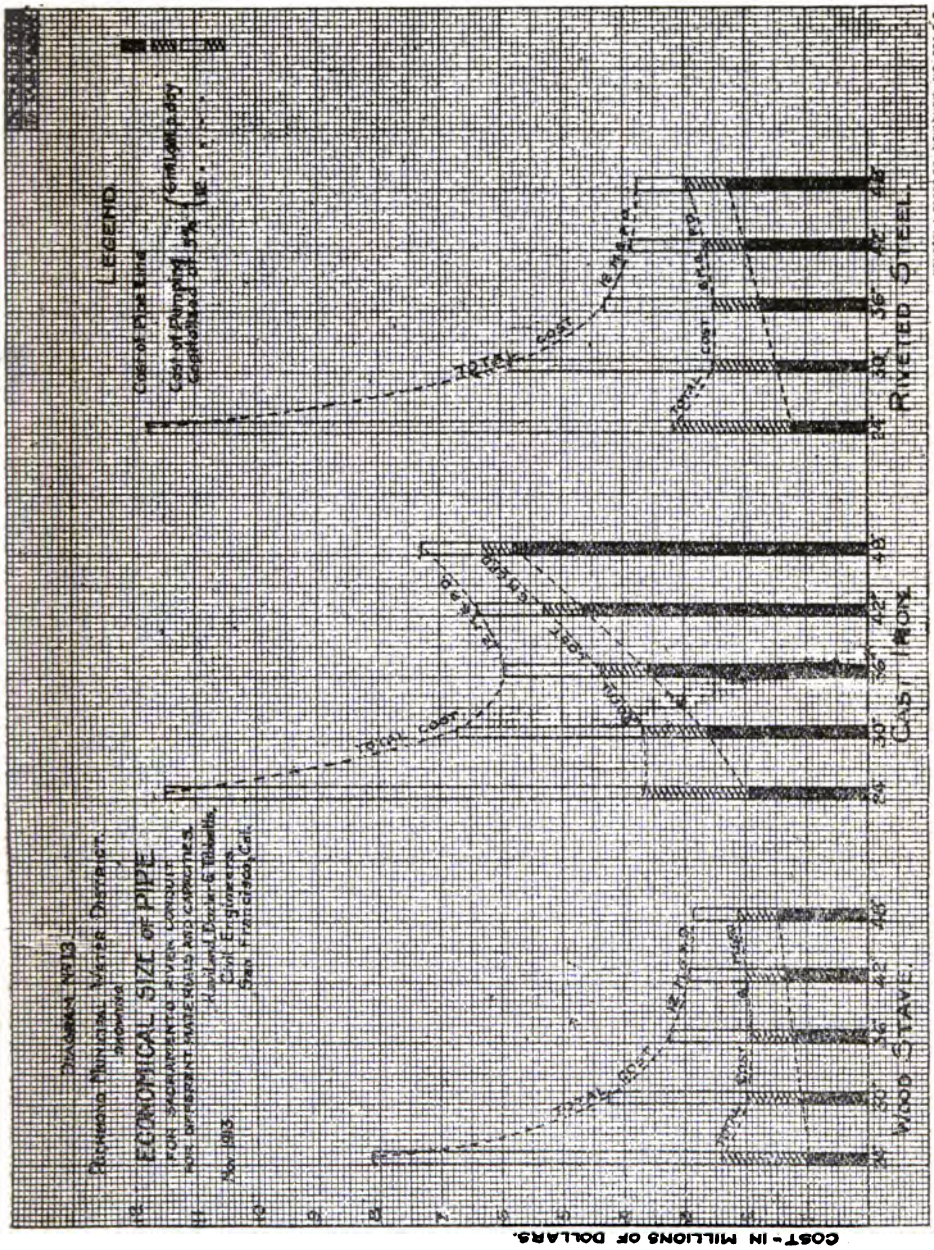
Section 1—Pumping Plant, Intake and Wharf at Toland's Landing—Intake.

The intake will consist of a concrete well or shaft, 6 feet in diameter, and about 24 feet deep. It will be supported on a pile foundation with the bottom at about elevation 7, or 8 feet below extreme low water. The intake well will be about 50 feet from the shore at a point where the banks are steep, so that the water is ordinarily at least 10 feet deep at low stages of the river. Two sluice gates will be provided in the walls of the intake well, set at different elevations so that water can be taken from the river at different depths as desired. The concrete structure will be surrounded and supported by a pile structure about 15 feet square, which will also form the support for vertical screen bars, consisting of wooden bars set edgeways with a 2-inch clear spacing. In addition to this, iron gratings will be placed in front of the sluice gate openings. Operating stands for the sluice gates will be on the deck of the timber wharf directly above the intake well.

From the concrete intake well, water will be carried to the shore through a 48-inch riveted steel intake pipe placed so that its top will be about 1½ feet below extreme low water. This steel intake pipe will rest on the wooden trestle supports of the superstructure of the timber wharf. It will discharge into a reinforced concrete culvert 4 feet square leading to a sump beneath the floor of the pump house from which sump the intake pipes will lead direct to the pumps. The sump will always be filled with water and together with its connection with the river will always be below low water, permitting the suction pipes from the pumps to be very short and direct.

Pumping Machinery.

The pumping machinery will consist of horizontal, high duty, centrifugal pumps, directly connected to horizontal electric motors. When the ultimate capacity of the system is reached with the conduit delivering a maximum of 15,000,000 gallons per day, reserve capacity of 50 per


ECONOMICAL SIZE OF PIPE
LEGEND
RIVETED STEEL
CAST IRON
WOOD STAVE
COST - IN MILLIONS OF DOLLARS.

cent. will be provided at the pumping plant, so that the total capacity of the pumps will then be 22,500,000 gallons per day or 15,600 gallons per minute. The ultimate design will consist of four units, two with a capacity of 7,500,000 gallons per day, and two with a capacity of half this amount. The larger units will be 14-inch pumps with 600 horsepower motors. The smaller units will be 10-inch pumps with 350 horsepower motors.

With the maximum delivery of 15,000,000 gallons per day the total head against which this pumping plant must operate will be about 238.5 feet. With a delivery of half this amount or 7,500,000 gallons per day, the total head will be about 125 feet. Of these total heads 85 feet represents the vertical distance which the water is raised, this being the elevation of the settling basins of the filter plants at Martinez, into which the open ends of the pipe deliver. The balance of 153½ feet for the ultimate capacity of the plant, and 40 feet for half this capacity represents the frictional loss through the 27½ miles of pipe line between the intake and the Martinez filters. The pumps when called to operate against the higher heads of the ultimate delivery, will contain two stages with motors of corresponding speed and capacity.

In order to reduce the suction head to a minimum the pumps will be placed in a pit about 4 feet deep, with the center of the shafts at elevation 15. The floor of the pit will then be just above extreme high water marks in the river, so that the pumps can be removed or repaired at all stages of the river and the suction head will be a minimum. The suction pipes will extend vertically downward through the floor of the pit and into the sump beneath the floor, where they will terminate in inverted cones into the suction sump. A water-tight cover will be provided for the manhole leading from the pump well to the sump.

To provide against temporary failure of electric power or the disabling of the motors, or other electric apparatus, a gasoline engine of 275 horsepower will be provided. This will be arranged with a belt connection with one of the larger pumping units which when thus operated, will be capable of delivering through the conduit about seven million gallons per day. As gasoline engines when not in operation deteriorate rapidly, the general rule should be made that the gasoline engine should be operated for about one day per month. This will insure its being kept in good order for emergency use. The engine should be belt connected to the nearest of the larger pumping units, as shown on Plate No. 9.

Building.

The pumping machinery will be housed in a reinforced concrete building of permanent construction and attractive design as shown on Plate No. 9. The site selected is a short distance upstream from Toland's Landing, opposite Baker's Point on Sherman Island. At this location a point of the Montezuma Hills rises abruptly from the water's edge. The building will be located on a lot one acre in area at the foot of the hills, with frontage of 150 feet and a depth of 290 feet. A firm clay foundation can be secured at this point. The building will be rectangular 51 feet long by 38 feet wide. Large window area

will be provided, giving excellent lighting facilities. Double doors, 8 feet in width will be located at the center of the front elevation. The pumping machinery will be in a pit 22 feet wide, and 35 feet long, depressed 4 feet below the elevation of the main floor, and reached by two convenient flights of stairs. Special tool rooms, wash rooms, etc., will be provided for the convenience of employees. A 5-ton travelling crane will control the entire floor space, for convenience in installing or moving machinery or supplies.

Wharf Directly in Front of Building.

A timber wharf will extend out into the river, with its outer edge about 143 feet in front of the building. This wharf will be about 25 feet by 53 feet over all, and will form a convenient landing place for employees and supplies. The trestle bridge will also form a support for the intake pipe. An industrial bridge-railway track will occupy the center of the trestle bridge, and extend from a point inside of the pump house to the outer edge of the wharf. This will permit of machinery being handled in steamers direct to cars on the industrial track and by them transported within reach of the travelling crane in the pump house. The timber wharf and trestle bridge will be of standard construction, with plank floor and pile supports. There will be a 20-foot roadway along the river bank between the edge of the pumping plant and the trestle approach to the wharf.

Bank Protection.

In order to thoroughly protect the pumping plant foundations, wharf and intake from possible caving of the river banks, provision will be made for pile and brush bank revetment for a distance of 300 feet above the intake and 100 feet below. This bank revetment will be of standard construction with brush bundles 24 feet long, tied by scantlings and wire, to timber piles on 10-foot centers. The estimated life of this class of protection is 15 to 20 years and it can be very easily renewed or repaired.

Modification of Pumping Plant for Immediate Use.

For the immediate requirement of 6,000,000 gallons per day corresponding to a maximum delivery in the conduit of 7,500,000 gallons per day, a portion of the pumping machinery may be omitted, as the heads against which the pumps will be called upon to operate will be much less than that for which they were designed. One of the pump runners can be omitted on each of the pumps, and the motors can be made of smaller capacity than will be required for the ultimate design and can be later exchanged for larger motors as required. In order to have sufficient reserve machinery, however, for any emergency, it is believed that two of the smaller pumping units should be immediately installed complete, together with the one of the larger pumping units designed with auxiliary connections for use with the gasoline engine. The reserve gasoline engine should also be installed complete. As other portions of the pumping plant and accessories are impracticable to enlarge they should all be constructed at once under the ultimate plans.

Section 2—Conduit From Toland's Landing to Antioch Pumping Plant.

The total length of this section is about 5 miles, including two submarine crossings. The head on the pipe will vary from 230 to 275 feet. The larger portion of this is friction head, and will only exist when the conduit is delivering water at its maximum rated capacity of 15,000,000 gallons per day. When delivering water at only half this rate, the head on this section of the pipe will be between 150 and 160 feet. The conduit may be built of wood stave pipe, riveted steel pipe or cast iron pipe. Alternate estimates have been made for each class of construction. It will be the most difficult portion of the pipe line to construct and probably will have the shortest life. The greater part of its length will be over the peat lands of lower Sherman Island. Over this portion the foundations are poor, consisting of soft peat to an indefinite depth, incapable of supporting heavy loads. This material contains much organic matter which will cause unusually rapid corrosion of any metal in contact with the soil. It may be necessary to support portions of the pipe on special foundations and great care will be necessary to obtain an effective preservative coating.

Submarine crossings are planned for both the Sacramento and San Joaquin Rivers. The Sacramento crossing as the river now exists will be about 700 feet in length, with a maximum depth of about 40 feet. The government flood control work for widening out the mouth of the Sacramento River involves cutting off Baker's Point and dredging a channel which will ultimately be about 40 feet deep and 3,000 feet wide, requiring a submarine crossing of this length. This is one of the first pieces of work to be done by the government dredges and may be accomplished before the Richmond pipe line is built, otherwise this portion of the pipe line will have to be relocated after the government dredging is finished, an operation which might involve the use of emergency intake at Antioch during construction.

The submarine crossing of the San Joaquin River will be about one mile above Antioch and will consist of two portions separated by West Island. The first will be 1,000 feet long, and the second 1,800 feet and the maximum depth will be about 40 feet.

The pipes at the submarine crossings should be laid in a trench dredged in the bed of the river to a depth which will make them safe from scour and dragging anchors. The natural action of the river will quickly back fill such a trench after the pipe has been laid. If cast iron or riveted steel pipe is used, it is probable that some form of special joint suitable for submarine work will be necessary. If wood stave pipe is used, particularly continuous pipe, it is believed that it could be built continuously on a barge and allowed to settle to the bottom of the river without any special construction, except that the iron bands or wire might have to be extra heavy in order that the pipe would have sufficient weight to sink to the bottom of the river.

Section 3—Emergency Intake and Pumping Plant at Antioch.

At the south bank of the San Joaquin River about a mile above Antioch, an emergency intake and pumping plant will be provided

so that water can be pumped directly from the San Joaquin River into the pipe line. This intake will be on the Richmond side of the portion of the conduit, involving the submarine crossings and the poor foundation conditions on Sherman Island. The foundations and general location of the conduit from this point into Richmond are about as favorable as would be desired from the standopint of reliability.

The design of the intake and building of the pumping plant would be identical to the Toland's Landing pumping plant, except for slight changes on account of different topography. No machinery would be provided, but the travelling crane, machinery foundations, etc., would be in place so that the machinery could be quickly transferred from the Tolond's Landing pumping plant. As these two plants are separated by only 10 miles of navigable water, it should be possible, with the mechanical conveniences provided, to transfer the machinery from the Toland's Landing pumping plant and place it in operation with 48 hours' notice. When the system is financially able to do so, it is probable that duplicate machinery will be provided for this pumping plant as an additional safeguard.

San Joaquin River water taken from this source could be used satisfactorily for a large portion of the year, under present conditions. The location is far enough above Antioch so that the amount of chlorine content and sewage pollution in the river is materially less than at Antioch. It might be desirable during favorable seasons to use this intake for a considerable portion of the year, thereby saving in the cost of pumping. It would also be convenient for use during repairs or alterations on the weakest portion of the conduit, the portion from Toland's Landing to Antioch. It is even possible that economic considerations may make it desirable to use this intake for a few years, omitting for the present the Toland's Landing pumping plant, and the conduit across Sherman Island. If this were done, it is probable that the Martinez reservoir should be immediately built in order that additional equalizing storage would render it possible to discontinue the Antioch pumping plant, when the water was of unsatisfactory quality.

Section 4—Conduit From Emergency Intake at Antioch to Filtration Plant at Martinez.

Like other sections of the main conduit, this will consist of a 36-inch pipe, and may be built either as a wood stave pipe, riveted steel pipe, or cast iron pipe. It will be about 22½ miles in length. The total head when delivering water at its untimate capacity of 15,000,000 gallons per day will vary from nothing up to a maximum of about 200 feet. When discharging at half this rate, the head will vary from nothing to about 115 feet. Eighty-five feet of these heads is due to the elevation of the water in the settling basin of the Martinez filtration plant, and the balance is friction head caused by the resistance to forcing water through the pipe. The exact head at any portion of the pipe can be easily obtained by scaling off the vertical distances between the ground surface and the hydraulic gradient as platted on Plate No. 8. It will be seen that only a very small portion of the pipe line is under a head of less than 50 feet, and most of it is more than 100 feet. The minimum pressure thereby indicated being an im-

portant consideration in determining the probable life of wood stave pipe.

Section 5—Filtration Plant at Martinez.

The necessity for filtration has been dwelt upon in the first part of this chapter. The requirements regarding the desirable quality of the water to be supplied are described at some length in Chapter 4. The general features of the design of mechanical filters have been more or less standardized. The type of filter most suitable for the Richmond Water District is one of the mechanical gravity type, used in conjunction with preliminary sedimentation and coagulation basins. The general character of the proposed plant is shown on the accompanying Plate No. 10. The conduit will discharge directly into a sedimentation basin formed by throwing a dam or levee across a small ravine. This basin will also serve to equalize the delivery from the pumps, thereby simplifying the operation of the filters. From this sedimentation basin the water will be conducted to coagulation basins. There will be two such basins rectangular in plan, formed by lining an excavation with concrete. Each unit will have a capacity of 300,000 gallons. In these basins the water will be mixed with a coagulant. It will pass from these basins directly to the filters, of which there are six units proposed for immediate construction, each unit being 20 feet by 27 feet in plan, by 11 feet deep. The filtered water will pass into a filtered water reservoir with a capacity of 600,000 gallons, partly under the filter beds, and partly with an extension on the side of the filter house opposite the coagulation basin. A reinforced concrete head house of attractive design will be provided for a store room, lockers and office and on the second floor a laboratory and coagulant mixing room. This building will be about 20 feet by 64 feet in plan. A filter gallery with suitable building and operating tables will be back of the head house, between the filter beds. This will contain the usual equipment of valves, piping and the latest design of electric and hydraulic controls for all parts of the plant.

The general location of the filters will be on a flat space, a short distance above Martinez, just above the baseball grounds. This is a most suitable location as regards elevation and topography. If it proves impractical to obtain the property desired on satisfactory terms, however, there are a number of other locations in the vicinity which would also be satisfactory.

The detailed design and operation of the proposed plant has not been worked out. This is a matter which would require very careful consideration and further examination of the quality of the water to be filtered. In accordance with the best practice, it is proposed that the plant should ultimately have a reserve capacity of about 50 per cent or a total of 18,000,000 gallons per day, in order to insure a uniform delivery of 12,000,000 gallons per day. This requirement is usual because of the intricate mechanical apparatus involved, which is liable to get out of order, and because of the fact that certain units of the filters must be temporarily put out of service for cleaning and repairs. For the immediate estimated consumption of 6,000,000 gallons per day, the capacity of the filters will be as shown on Plate No. 10, or equivalent to 9,000,000 gallons per day. It is not deemed necessary to provide

filter capacity for delivering 7,500,000 gallons per day during the maximum month at the usual rate of filtration. This because the maximum month will occur in the summer and at the same time that the water in the river is more free from silt and suspended matter. At such times the filters may be operated at a higher rate and the excess requirement taken care of in this way. As further capacity is required, the plant can be added to or duplicated by constructing additional units.

Section 6—Booster Plant at Martinez.

This will be a separate structure, housed in a separate building immediately adjacent to the filter plant. The building and machinery will be almost identical with the Toland's Landing pumping plant. The plant will, like the former, also be equipped with auxiliary gasoline engine. The pumps will have their intake pipes taking water directly from the filtered water basin. The maximum head against which the pumps will have to operate will be approximately the same as for the Toland's Landing plant. As the total length of pipe through which they will force the water is less than for the Toland's Landing plant, the proportion of the total head caused by frictional resistance to the movement of the water is less. The frictional head depends upon which of the alternate alignments is chosen for the pipe line, whether the bay shore route or the alternate inland route with the tunnel. If the former is used, the total head against which the plant will operate with the ultimate delivery of 15,000,000 gallons per day will be 291 feet, of which 107 feet will be friction head. The balance of 184 feet represents the vertical distance through which the water will be raised from the elevation 70 of the filtered water basin at Martinez to the elevation 254 of the Richmond Junction Heights reservoir. If the alternate inland route is used, the maximum head against which the pumps will operate will be 281 feet, or 10 feet less than for the shore route. Of this 281 feet, 97 feet will be friction head, the static head being the same as for the alternate route. For the present capacity of 7,500,000 gallons per day the maximum head for the shore route will be 196 feet, of which 31 feet will be friction head, and the balance of 165 feet will represent the vertical height to which the water will be raised from the elevation 70 of the Martinez filters, to the elevation 235 of the Richmond Junction Heights reservoir. If the alternate inland route is used, the total head will be six feet less, the difference being entirely in the friction head.

The portions of the pumping plant which may be omitted for the present reduced delivery, will be exactly as described for the Toland's Landing pumping plant.

Section 7—Conduit From Booster Pumping Plant to Martinez Reservoir.

This section is short, being only 1¼ miles in length. It is under a very high head, ranging from 250 to 300 feet. Like other portions of the pipe line, it may be constructed of either wood stave, riveted steel or cast iron pipe. It will discharge directly into the Martinez reservoir when the latter is constructed. Prior to the construction of the Martinez reservoir it will be continuous with the next section of pipe line

if the shore route is used, or with the pressure tunnel if the alternate inland route is used.

Section 8—Martinez Reservoir.

This is to be located in a side canyon about 1½ miles northwesterly along the shore of Suisum Bay from Martinez. It will be about a half mile from the shore of the bay. The water will be stored between elevations 290 and 350. The general topography is shown by the plan on Plate No. 10. On this plate are also shown curves and tables giving the area and capacity at various elevations. The lowest point beneath the crest of the proposed dam will be at elevation 270, and the top of the proposed dam will be at elevation 360, giving a dam 90 feet in height. With the water at elevation 350 the reservoir will have a capacity of about 60,000,000 gallons. The general type of earth dam is similar to that described in detail in the following chapter for the Richmond Junction Heights distribution reservior. The up-stream face will be paved with concrete, on a 1 on 3 slope. The top width will be 20 feet. The downstream slope will be 1 on 2½, interrupted by two 20-feet berms. The details of the dam construction have not been worked out, as it is not proposed to build the dam and reservoir at present, but to defer its construction until the larger delivery is desired, in which case additional storage should be provided. The Martinez reservoir site furnishes the cheapest storage possibilities anywhere on the route of the conduit.

SECTION 9—CONDUIT FROM MARTINEZ RESERVOIR TO RICHMOND.

Two alternate alignments have been worked out for this portion of the conduit as follows:

9—S: Along the shore line following the right of way of the Southern Pacific Railroad, through Port Costa and Crockett to Pinole, and thence along the County Road to Richmond.

9—I: An inland route as far as Pinole, passing direct from the Martinez reservoir through a tunnel under the Franklin Ridge, thence down Rodeo Creek to Pinole and along the County Road to Richmond.

In the following chapter general estimates are given for both these two alignments. Their general course is shown on Plate No. 8, with profiles of each line. The proposed tunnel underneath the Franklin Ridge is about three miles long, and its construction would be costly. A saving would be effected, however, in the pipe line which might fully offset the additional cost of the tunnel. The shore route is about 1¾ miles longer than the inland route, and the pressure on the pipe will average much higher, partly because the ground on which it is located is lower, and partly because the hydraulic gradient is higher, especially with the ultimate capacity of 15,000,000 gallons per day. When the ultimate capacity is reached, a large portion of the shore route would be under heads between 275 and 350 feet. These heads are close to the limit for certain types of construction. The cost of pumping through the inland route would be considerably less than through the shore line route, especially when the ultimate capacity

of the pipe line is reached. The principal argument in favor of the shore route is that it would pass through, and adjacent to, a number of industrial communities and large manufacturing concerns along the shores of the Bay, which should prove profitable water customers, especially in the early years of the system's development. Against the inland route is also the possibility of loss of time in the construction of the tunnel. For much of the shore line the only feasible right of way is now occupied by the double track, main line of the Southern Pacific Railroad. It is doutful if there is any practieal method of safely constructing a pipe line of the size and pressures required in conjunction with the railroad.

Tunnel.

The proposed tunnel would be built as a pressure tunnel so that it would be necessary to build a pipe line for the same section. It would be placed at about elevation 250 feet, or approximately the elevation of the distributing reservoirs in Richmond, and in a position such that it can be fed by gravity from the Martinez reservoir. At this elevation its length as determined by scaling from the best maps available is about 15,000 feet. The tunnel would be driven in solid rock for the greater part of its length, with a cross section as shown on Plate No. 10 as small as it is practicable to use. It would be lined with reinforced concrete throughout, designed to withstand the earth loads from without, and to withstand an internal pressure equivalent to a head of about 80 feet of water. An extended study has been made of the cost and progress records of many similar tunnels built in recent years, especially those of the Los Angeles and Croton Aqueducts. In order that the tunnel might be finished as soon as other protions of the work, that is, within eight to twelve months, it is proposed to sink two shafts at intermediate points along the line, and to carry on the work from six headings. The northeastern portal should be in the canyon just below the proposed Martinez reservoir, and as it is a part of the first construction it should be located so as to be just outside of the proposed dam. Until the reservoir is built it may be advisable to run an open end pipe up the side of the hill to a point well above the hydraulic gradient, of the conduit. Such construction would serve as a surge pipe, and would tend to lessen the dangers from water hammer on all portions of the conduit.

Richmond End of Conduit.

For estimating purposes, Section 9, the lowest section of the proposed Sacramento conduit, will end at Nevin Avenue, near the Southern Pacific Railroad in Richmond. At this point the 36-inch pipe line ends, the delivery of water being continued in 30-inch and 24-inch pipes, branching to either side. Below this point the mains in the City of Richmond, together with the distributing pipes, reservoirs, etc., will be discussed in detail in the following Chapter No. 8, under the heading of "Distributing System."

CHAPTER No. VIII.

Distribution System

ELEMENTS OF THE DISTRIBUTION SYSTEM.

By the distributing system is meant the system of main, and lateral pipes, which distributes water to the immediate consumers, together with the distributing and balancing reservoirs directly connected to the mains and immediately adjacent to the area served.

A distribution system is more or less independent of the source of supply. In the present instance, however, the source of supply will determine the point of entry of the main conduit and the necessity for a large distributing and equalizing reservoir. If the Sacramento supply is adopted as recommended, it will be assumed for estimating purposes that the conduit terminates at the end of the 36-inch conduit, which is continuous with the 30-inch and 24-inch mains, branching to the distributing and balancing reservoirs. Water will also be distributed from laterals branching from the 36-inch main inside of the city limits, and in fact may be distributed from any point on the 36-inch conduit in front of the filters near Martinez.

The detailed topography of the Richmond Water District has been discussed in Chapter I. The principal portion of the urban district to be served with water is on a flat and relatively low area between ranges of high hills. This topography offers exceptionally favorable conditions for the design of a distribution system which will give excellent fire protection from high level, gravity reservoirs. The main features of the proposed distribution system are shown on the accompanying Diagram No. 14. When finally developed, the business section in the vicinity of Macdonald Avenue, between the railroads, may receive at times of maximum draft, water supplied from three directions: the main distributing reservoir on the hills to the east of town, the balancing reservoir on the hills to the west of town, and the main supply conduit from the Martinez pumping plant or the Martinez reservoir. This arrangement will enable the maximum supply to be delivered for fire fighting purposes in the business section under the best conditions possible for conserving the head and maintaining an ample delivery at effective pressures.

CAPACITY OF DISTRIBUTION SYSTEM.

Variation in Consumption.

Tables Nos. 16 and 17, at the close of Chapter II, give the estimated per capita and total consumption in the Richmond Water District up to the year 1955. The figures tabulated therein are estimates for the average daily consumption throughout the year. The very considerable variations from this average must be carefully studied in designing the various parts of the distribution system and to a lesser extent of other portions of the plant. It is necessary to estimate the monthly, daily and hourly variations, and particularly the maximum

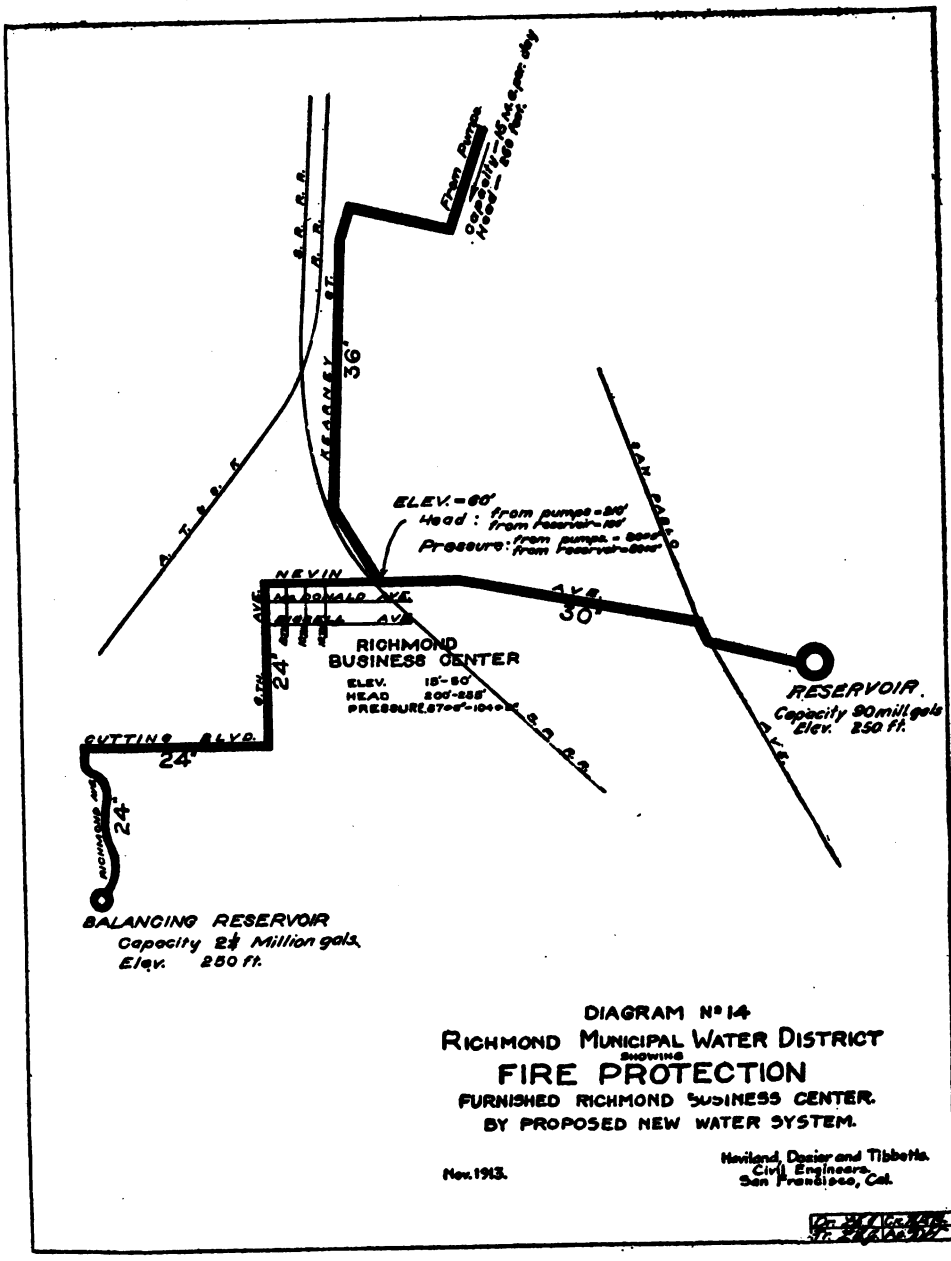


DIAGRAM Nº 14

RICHMOND MUNICIPAL WATER DISTRICT

SHOWING

FIRE PROTECTION

FURNISHED RICHMOND BUSINESS CENTER.

BY PROPOSED NEW WATER SYSTEM.

Nov. 1913.

Haviland, Dozier and Tibbetts.
Civil Engineers.
San Francisco, Cal.

rates of consumption which may obtain for shorter periods. The maximum monthly rate is chiefly used in designing the pumping plant, conduits, and filters; the maximum daily rate in designing the distributing and balancing reservoirs; and the maximum hourly rate in designing the distributing system and balancing reservoirs.

The variations in Richmond ought to be less than in most California cities. The climate is very equable and the range of temperature small. The very large portion of the total water consumption used for industrial purposes will also tend to make the demand more uniform. Leakage, wherever it exists, is nearly constant, and therefore tends to decrease the variations.

Monthly Variations.

In nearly all localities the rate of consumption reaches a maximum in the summer, owing to the warmer weather. In California this is particularly true, because owing to the nomal period of drought during the summer months, the use of water for street and lawn sprinkling is much in excess of its use for these purposes during the rainy season. The higher summer rate usually extends over several months. It is, therefore, impracticable to provide storage sufficient to equalize the monthly variations and all portions of the plant should have enough excess capacity to provide for the average rate during the maximum month. From a careful study of data taken from other cities it is concluded that the maximum monthly rate may be safely taken at 125 per cent of the average, and that there are apt to be several consecutive summer months averaging 115 to 120 per cent of the yearly average.

Daily Variations.

The maximum daily consumption is always somewhat in excess of the average for the maximum month. This is caused by a variety of conditions, some accidental and some constant. The maximum daily rate usually occurs in the month of maximum consumption, and may be taken as above the average for that month by 10 to 15 per cent. It is estimated that the maximum daily consumption in the Richmond Municipal Water District will be 110 per cent of the average for the maximum month, or 137½ per cent of the average daily consumption throughout the year.

Hourly Variation.

If there were no waste or leakage, the domestic consumption during several hours of the night would be very small. Leakage and waste, however, are nearly constant, and much of the consumption for industrial uses is constant throughout the day. During the summer, when the monthly rate is high, the hourly rate is also apt to be high, because of the use of water for lawn and street sprinkling, during the day. To curtail this, it is sometimes required that lawn sprinkling be done at special hours. In large cities street sprinkling and washing is also frequently done at night for traffic convenience. These practices tend to minimize the hourly variation. For the Richmond Water District it is estimated that the maximum hourly consumption is 1⅓

of the average hourly consumption of the maximum day, or 183½ per cent of the average hourly consumption throughout the year. This is equivalent to assuming that on the day of maximum consumption all of the water might be used at a uniform rate in 18 hours.

Fire Consumption.

As discussed in Chapter IV, the ultimate maximum fire draught is estimated to be 4,100 gallons per minute, equivalent to about 5,900,000 gallons per day. Experience shows, however, that the supply need not be maintained at the above rate longer than about six hours. Hence the maximum fire consumption per day may be estimated at 1,475,000 gallons, or say 1½ million gallons, or 12½ per cent of the ultimate maximum daily consumption. The maximum hourly consumption for fire purposes, however, should be estimated at the above rate of 5,900,000 gallons per day, or say 6,000,000 gallons per day, or 250,000 gallons per hour, equivalent to 50 per cent of the ultimate average daily consumption for which the plant is designed. The total amount of water used for fire-fighting purposes is so small that its effect on the monthly variation is negligible.

Summary of Required Capacity.

The proposed works will be designed with an ultimate capacity of 12,000,000 gallons per day, and a present capacity of 6,000,000 gallons per day, which is the predicted consumption from the municipal system in 1820. The various parts of the plant will be proportioned with ample allowance for temporary and sustained overdraught, so as to deliver these amounts with certainty under the required conditions of practical service.

The following table shows the variations in consumption and the required capacity of various parts.

Table No. 40—Capacity of Proposed Plant.

Period	Percentage of Normal	Capacity: Present Average Daily Rate	Capacity: Ultimate Average Daily Rate
Year, 100%		6,000,000	12,000,000
Maximum Month, 125%		7,500,000	15,000,000
Maximum Day, 110% of 125% = 137½% + 12½ (for fire) = 150%		9,000,000	18,000,000
Maximum Hour, without fire consumption, 133⅓% of 137½% = 183⅓%		11,000,000	22,000,000
‡Maximum Hour, with fire consumption, 175% + 50% (for fire) = 225%		13,500,000	27,000,000

‡The last figures provide for the total fire requirements combined with domestic consumption as arbitrarily reduced from 183⅓% to 175% because of the extreme improbability of the absolute maximum domestic consumption occurring simultaneously with the maximum fire draught. (During a general conflagration it is usual, by closing the valves in the distribution system, to curtail the supply furnished to districts not endangered.)

STORAGE RESERVOIRS.

Need for Storage.

The conservative design of a distribution system in order to sustain the delivery during temporary interruption to the supply, requires a considerable amount of storage close to the point of consumption, that is near the City. This storage should, if possible, be at sufficient elevation to supply water by gravity at the normal pressure for which the system is designed. It is required as a safeguard where water is obtained, as in the present instance, from a distant source, to guard against the temporary failure of the long conduit, pumping plants or filters from earthquakes, washouts, accidents to machinery or other unforeseen contingencies. It is also required for fire protection, as the underwriters' standards for minimum insurance rates in a city protected by a gravity supply, require a storage of at least five days' maximum consumption.

Economical considerations also require storage in order to equalize the variation in the hourly, daily and weekly consumption. If storage is provided sufficient in amount to equalize the variations in consumption for a month, then the portions of the plant above such storage need have a capacity sufficient only to supply at a uniform rate the average consumption throughout the month rather than sufficient to meet the maximum requirements. In the present instance, this reduced capacity applies to the pumping plants, filters and main conduit, which together represent about three-fourths of the cost of the entire project.

Advantages of Balancing Reservoir.

The advantage of having two balanced reservoirs on opposite sides of the distribution system is very much the same as that obtained by designing the service laterals to be fed from mains at either end. One or more of these auxiliary reservoirs balanced against the main distributing reservoir and placed in parts of town distant from the entering point of the main supply line, furnish a flow in the mains by more than one route toward the place of maximum draft. In this way the velocity in the mains during the period of maximum use is much reduced, as may also the length of pipe traversed by the bulk of the water in reaching the point of use. Thus the head lost is very much diminished. During the time of day when there is a maximum draft on the mains or during short periods of excessive draft, due to fire streams, a portion of the water is obtained from the balancing reservoirs which are again refilled as the immediate consumption falls below the normal. The use of these reservoirs will permit the use of smaller mains throughout, and will thereby effect a saving on a large number of pipes, which amounts to a greater sum than the cost of the reservoir.

Capacity of Main Distributing Revervoir or Reservoirs.

The main distributing reservoir will be designed with a capacity sufficient to meet the maximum requirements for the most favorable fire protection rates and sufficient to equalize the difference between the maximum daily and maximum monthly consumption.

Fire Requirements.

The standard requirements for a gravity system are for the reservoir or the source of supply to have a capacity of at least five days' supply for domestic and fire purposes. This will be interpreted as meaning five days at the maximum daily rate previously given, or 45,000,000 gallons for the present design. Ultimately, this should be enlarged as the demand increases, until when the full capacity of the system is reached it should contain 90,000,000 gallons.

Equalizing Requirements for Immediate Installation.

The maximum daily draft as previously given is estimated at 110 per cent of the average for the maximum month, excluding the requirements for fire. The maximum fire consumption, however, will last less than one day. Including this, and assuming that the maximum daily rate is maintained for 15 days, then the additional water required for the average maximum month would be 10 per cent. of 7,500,000 gallons per day for 15 days, a total of 15 x 750,000 gallons equals 11,250,000 gallons, add to this the maximum amount required to extinguish two conflagrations (3,000,000 gallons) and the total storage required for equalizing purposes is 14,250,000 gallons. This is about one-third of the required amount given above for fire protection to meet the lowest insurance rates.

The maximum daily variation could readily reach for half a month or longer, more than twice the assumed amount and still be equalized by the storage reservoir.

Capacity of West Side Balancing Reservoir.

As presently explained it is not proposed to build this structure at this time. It will ultimately be made large enough to equalize the hourly flow during a single day. If this requirement be met, then in case of temporary trouble with the main east side distribution reservoir, the system could still be continuously served, from the main conduit.

It will be made large enough to hold the maximum decrement which might otherwise accumulate, because of the excess of hourly consumption during a portion of the day over the average hourly consumption during that day. This capacity may be variously estimated. The analysis given shows that the average consumption for the maximum day is at the rate of 18,000,000 gallons per day or 750,000 gallons per hour, also that the maximum hourly consumption including the draft for fire protection is at the rate of 27,000,000 gallons per day or 1,125,000 gallons per hour. The excess hourly draught is then the difference between these two figures, or 375,000 gallons per hour. It is also estimated that this excess can occur for only 6 hours. The capacity of the reservoir can then be estimated as 6 x 375,000 gallons or 21,250,000 gallons per hour.

Another method of estimating the capacity of this reservoir is to make use of the observed fact that the hourly consumption is in excess of the average for the day, for about 14 hours per day, and is less than the average for about 10 hours per day. During the 14 hours in which it exceeds the average, it is about 120 per cent. of the average for the day. Taking the average hourly consumption of 750,000 gallons and assuming

an excess of 20 per cent. for 14 hours, gives the required capacity of the west side balancing reservoir as 2,100,000 gallons.

With the capactiy suggested above, it is believed that the insurance requirement of duplication of lines will be completely filled, as the distribution system will be fed from three separate sources—the west side balancing reservoir, the east side distributing reservoir and the 36-inch main conduit supplied directly by the Martinez pumping plant or Martinez Reservoir.

Any one of these sources will hold in reserve at a high elevation, sufficient water to extinguish a general conflgration.

West Side Reservoir Not Now Needed.

The west side balancing reservoir will not be necessary for a number of years. It is proposed to design the mains and laterals of the distribution system of size sufficient for the ultimate average daily capacity of 12,000,000 gallons per day. For a number of years before the consumption reaches this amount there will be a large excess capacity in the mains. With the large reservoir on the hills east of Richmond, sufficient pressure will be maintained in the distribution system without the use of the balancing reservoir. Its construction should hence be deferred for economic considerations. It would be well, however, to obtain at once the land required, in order that the reservoir might be constructed as planned whenever it became apparent that the pressures during periods of unusual draft fell below the desirable requirements.

Elevation of Reservoirs.

The elevation of the distributing reservoir and the west side balancing reservoir will be approximately the same, with operating levels at about elevation 250. This elevation will govern the pressure throughout the distributing system. Provision should be made for automatically cutting off the supply when this high water elevation is reached. Both reservoirs have been designed so that they will have the bulk of their storage capacity close to the required elevation. In the main distributing reservoir at Richmond Junction Heights, the water level will be at elevation 234 for the present capacity of 45,000,000 gallons, and 254 for the ultimate capacity of 90,000,000 gallons. The west side balancing reservoir will have its bottom at elevation 237 and its maximum high water surface at 254. Its construction as previously indicated should be deferred until the consumption has exceeded 6,000,000 gallons per day, and the required storage in the Richmond Junction Heights distributing reservoir exceeds 45,000,000 gallons, requiring the water level in the reservoir to be raised and its capacity enlarged. The capacity and area of the main reservoir up to any given elevation are shown on the capacity and area curves of Plate No. 11.

Possible Separate Fire Protection.

With water in the reservoirs, at these elevations, 80 to 100 pounds static pressure will be maintained throughout the distribution system. One-half of this amount would be sufficient for all purposes except fire protection. The additional cost, however, of pumping all the water used an extra 100 feet is very small, probably not exceeding $5.00 per

million gallons, or ½ cent per 1,000 gallons. The certainty of having water in the distribution system at all times, under pressure ample for fire protection much more than justifies the additional cost of pumping and some additional cost of maintenance in the distribtution system caused by the higher pressures. In general the pipes of the distribution system can be made smaller because of the higher pressures.

Standard plumbing fixtures as furnished at the present time are not injured by such pressures. Old and weak plumbing fixtures can be relieved by pressure reducers at individual houses if required.

Inasmuch as water must be stored at approximately the elevations given to give gravity fire protection, systems designed to distripute water for domestic consumption at lower heads would require duplication of the storage reservoirs at lower elevations. There would also be uncertainty and loss of time in opening valves at the outbreak of a fire in order to throw into the distribution system the higher reservoirs. At such times a sudden increase of pressure would be thrown on to the plumbing fixtures and might be more injurious than steady and regulated application of higher pressures.

CONSTRUCTION OF DISTRIBUTION RESERVOIR.

Location.

The proposed main distributing reservoir is located at a site very excellently adapted for its purpose. The reservoir will be formed by an earthen dam thrown across a deep ravine just north of Richmond Junction Heights, and half a mile east of the junction of San Pablo and Macdonald Avenues. It will be necessary, if the reservoir is placed as planned, that all of the blocks Nos. 63 and 37 and a portion of Block No. 36 of Richmond Junction Heights be acquired, and that about an equal amount of land be acquired in Alta Punta Terrace tract, just north of the blocks named.

The topography is such that the desired capacity can be obtained with an economic height and length of dam. The elevation is sufficient to insure proper pressures for a gravity supply for the city. The contour of the ground is such that the capacity of the reservoir can be made to fit the immediate needs, and can later be economically enlarged to the capacity for which the ultimate system is designed.

The general location opposite the center of the built-up portion of the district is well adapted for the maximum efficiency of service. It is also far enough away and high enough above the congested and industrial districts so that it can be built as an open reservoir without serious danger of accidental pollution. The dam would be opposite Macdonald Avenue in plain sight from the business district of Richmond.

Dam.

The distribution reservoir will be formed by an earth dam, with a maximum height of about 80 feet, as ultimately constructed, with a 90,000,000 gallon capacity. For the present capacity of 45,000,000 gallons it will have a maximum height of about 60 feet. The material upon which the dam will be founded appears to be rock, overlaid to a varying, but not great depth, with earth. Solid rock is probably less than 20 feet below the surface. The earth dam will have slopes of 1

on 2½ on either side, with a 20-foot berm on the rear side at about mid-height. The top of the dam will be 30 feet in width, with provision for a 20-foot roadway. The clear height of the crest of the dam above the water surface will be seven feet. The upstream face of the dam will be faced with concrete, continuous with the reservoir lining, and with a toe wall carried down to solid rock. The dam will be constructed chiefly of material excavated from the reservoir. The contours of the finished bottom, as shown on Plate No. 11, show conditions in the reservoir as they would exist if the dam were built to its ultimate height. If the lower dam required under present conditions were built, the finished surface would be shown correctly only below the 234 foot contour, the latter being the water level for the present required storage of 45,000,000 gallons. If the dam were raised as indicated, material would be obtained by the excavation of a berm around the edges of the smaller reservoir. This could probably be done without emptying the reservoir.

Reservoir Lining.

The entire reservoir will be lined with a concrete slab three inches in thickness, reinforced by steel wire mesh. This lining will be carried around the circumference of the reservoir and three feet above the high water mark. It will be continuous with the front facing of the earth dam. Expansion joints will be provided as required. Unless an exceptionally good quality of hard, impervious rock were uncovered, the reservoir lining would be required to preserve the quality of the water from deterioration.

Controlling Works.

The controlling works will consist of a reinforced concrete intake tower near the south end of the dam, connected to the shore with a foot bridge, a concrete spillway and concrete-lined spillway ditch, pipes through the dam, valves, and other necessary accessories.

The concrete intake tower will be circular in plan, with a total height of about 75 feet. Gates will be provided so that water may be drawn off at different levels as desired. The intake pipe will consist of a reinforced concrete culvert entering the reservoir at the intake tower. Ordinarily this will be operated with the end open, permitting the water level in the reservoir to fluctuate through a certain small range as the draught exceeds or falls short of the amount furnished by the pumps. A gate at the extreme bottom will permit of emptying the reservoir and blowing off any silt or settled matter that may collect at the bottom.

A concrete spillway is provided at the south end of the dam. As the watershed lying above the reservoir is very small, provision is made on the reservoir berm for diverting the runoff from the watershed around the reservoir and dam. The capacity of the spillway has been made equal to twice the maximum capacity of the pipe line supplying the reservoir. It is a reinforced concrete weir 10 feet long, spilling into a reinforced concrete flume, five feet wide, and 18 inches deep. It will have the required capacity of 15,000,000 gallons per day, or 10,500 gallons per minute, with the water about nine inches over the weir, or at

elevation 254 feet nine inches in the reservoir. The flume will be rectangular, with concrete sides four inches thick, and floor six inches thick, reinforced with wire mesh. It will conduct water from the spillway down the slope of the ravine to a point of discharge safely beyond the lower toe of the dam. For the immediate construction the spillway weir will be placed at elevation 234 feet.

CONSTRUCTION OF WEST SIDE BALANCING RESERVOIR.

Location.

The west side balancing reservoir will be located on the rounded crest of a rocky hill on the Potrero range, west of town, about three-quarters of a mile southeast of the intersection of Cutting Boulevard and Ashland Avenue. This is on the side of town almost directly opposite the main distributing reservoir and is favorably situated to supply excess demands for fire protection and other purposes to the Point Richmond business section.

Construction.

The reservoir will be circular in plan with a diameter of 130 feet. A portion of its volume will be obtained by excavating, probably in solid rock. The excavated material will be used to construct embankment for further increasing the capacity of the reservoir. It will be lined with reinforced concrete four inches thick throughout, with 1 on 1 slopes in the rock excavation, and 1 on 2½ slopes on the embankment. The top of the embankment will be three feet above the water surface. The bottom will be at elevation 237 and the high water level at elevation 254, the same as proposed for the main distributing reservoir, with its ultimate capacity of 90,000,000 gallons. The storage in the balancing reservoir will then be in the 17-foot depth, between elevation 237 and 254. In about this same range of depth will be the increased storage from 45,000,000 gallons to 90,000,000 gallons of the east side distribution reservoir. The balancing reservoir will be connected to the mains by a 24-inch pipe, reaching through the embankment to the bottom of the reservoir and provided with proper valves. A concrete spillway will be provided by a weir six feet long, leading into a 24-inch sewer.

FIRE PROTECTION.

Quantity of Water Required.

For fire protection purposes (See Chap. IV) it has been assumed that when the population equals that given in the table for 1945, and the system has been developed to its full capacity, that the maximum number of fire streams which will be needed simultaneously throughout the entire city will be 20, of which 8 will be streams of 250 gallons per minute each, and the balance streams of 175 gallons each.

For any district which comprises, say, one-fourth in area of the city, it is estimated that 8 streams would be needed simultaneously, of which 4 will be streams of 250 gallons per minute each, and the rest, streams of 175 gallons per minute.

For the design of the distribution system in the residence districts it is estimated that a maximum concentration of four 175 gallon streams on any point will be needed.

For the business section it is estimated that the maximum draft for fire protection purposes on any one square will be 14 fire streams delivered simultaneously, and that every point should have at least 4 streams which could be applied through a hose length not exceeding 300 feet.

Pressures.

Provision has been made in the design of this system for furnishing the business district the full amount of water specified for fire protection at the minimum pressure of 80 pounds per square inch, required by the Board of Underwriters for their basic rate. In none of the territory supplied below 100 feet elevation does the pressure fall below 50 pounds. These are working pressures at the hydrants furnished under conditions of maximum draft on the mains.

Practically all of the development in the district is below the 150-foot contour. The territory lying on the hills between the 100 and 150-foot contour is naturally residential property and not extensive, so that the pressure furnished should give satisfactory results. For ordinary consumption outside of fire demands, the pressures have been kept sufficient so that in a building 175 feet high in the business section, the working pressure will not be below 30 pounds per square inch.

In order that these pressures may be obtained in practically all of the territory, it is necessary with the distribution system as planned, that the average surface of the water in the reservoir should not be less than 200 to 250 feet elevation. This elevation gives the desired pressure in everything but a small portion of the city lying along San Pablo Avenue, between Macdonald Avenue and the County Line.

It is not desirable to have pressures exceeding 120 pounds per square inch, as the frequency of the breakages and the strain on fittings is uneconomical. For domestic purposes a pressure at the service taps of 45 pounds per square inch, excepting in the case of tall buildings, is satisfactory. No pressure for any purpose at the service taps should be less than 25 pounds per square inch. In case of tall buildings an effective head at the service taps of 70 feet, plus the height of the buildings is satisfactory.

Pipes and Hydrants.

The requirements for pressures and quantities given above, in the business district require hydrants being placed not over 300 feet apart on mains of sufficient size. Six-inch pipe or larger has been used in the entire city where more than one hydrant is to be placed on a line. In no place has there been any pipe designed for fire protection purposes less than four inches in diameter, and this small size is used only in localities where one hydrant is to be served within 500 feet of a line six inches or larger. At nearly every hydrant the draft on the pipe will be from two directions, thereby reducing the necessary diameter.

DOMESTIC CONSUMPTION.

The requirements for fire protection are greatly in excess of those for domestic consumption, except on the very large mains. Hence the former requirement has fixed the sizes of the distribution system, except for small pipes in the residence district used for domestic supply only. Even with smaller pipes a design has been worked out wherever possible so that the pipes will be fed from two directions, thus preventing objectionable dead ends, and maintaining better pressures and capacity in the pipes. In general, in the residence district, the designing standards have permitted the use of a large amount of short lengths of 2-inch pipe fed from both ends by 6-inch mains.

For domestic draft, it has been estimated that the heaviest concentration of consumption would be that of 100 people to each 100 feet of pipe, and that they would consume water for a period at a maximum rate of three and one-half times the average daily per capita consumption of the entire city. Also, with discretion, a standard has been used for semi-business, apartment houses, and more compactly built up residential districts, of 50 people per 100 feet of pipe with the same maximum consumption for a short period. For the ordinary residential districts a rate of 20 people per 100 feet of pipe using water at the above rate has been used.

DETAILED DESCRIPTION OF MAINS AND LATERALS.

The following description gives the locations and sizes proposed for the mains when the system is ultimately developed to its full capacity, serving all of the present subdivided portion of the district. All the mains, laterals and hydrants are shown in detail on Plates Nos. 4 and 5, with the location and sizes of each piece of pipe. The immediate installation recommended is shown on Plates Nos. 3 and 5 and consists of portions of the ultimate system chosen so as to supply the present populated or improved districts. In general, provision is made for supplying every block in which there are two or more buildings, isolated locations being excepted. As new improvements are made, the system will naturally be gradually extended, in which case the extensions should be made in conformity to the design, shown on Plate Nos. 4 and 5.

Mains.

The Sacramento conduit will enter the urban portion of the district at the north end at San Pablo. After crossing San Pablo Creek it will turn westward to Kearney Street.

The 36-inch main will then run south along Kearney Street as far as Clinton Street, and will continue southeast along the diagonal street parallel to the Southern Pacific Railroad to Nevin Avenue. From this point a 30-inch main will run the length of Nevin Avenue from the Southern Pacific Railroad east to San Pablo Avenue, and will continue about half a mile eastward up to the distributing reservoir. This line will constitute the main artery of the distribution system, and will, during times of excessive demand, receive water from both ends. If the demand for water exceeds the capacity of the pumps, or if the pumps are

shut down, water will flow westward through the Nevin Avenue line from the reservoir. If the pumps furnish water at a higher rate than the immediate demands, water will pass eastward through this main and replenish the reservoir. The second main artery of the system is that which leads from this first main to the balancing reservoir in the west side of town. This will be a 24-inch main and will run west along Nevin Avenue to 6th; south along Wine to 6th and Cutting Boulevard, and west along Cutting Boulevard to Wine Street. From here the 24-inch pipe will continue along Richmond Avenue and in a general southerly direction and will connect with the balancing reservoir on the hill about ¾ of a mile southerly from Cutting Boulevard.

From this triangular system of main arteries, main pipes of sizes somewhat smaller, will extend out in a series of loops so that there are no dead ends, but all pipes will be fed from both ends.

Beginning at the north, a 10-inch main will connect with the 36-inch main on Kearney Street, about opposite the center line of the Sunnyside Tract; thence it will extend easterly along the street forming the south line of Richmond Pullman Pueblo Tract, until the southeast corner of the tract is reached; thence along a street northeasterly to Alvarado Street; thence along Alvarado and San Pablo Avenue in a general southeasterly direction to Lincoln Avenue.

Along San Pablo Avenue from Lincoln Avenue to Nevin Avenue will be a 16-inch main, connecting with the 30-inch lead from the east side reservoir at the latter point.

The next large main will be on Lincoln Avenue. It will be a 10-inch pipe, tying across from the 36-inch main on Kearney Street to the 16-inch main on San Pablo Avenue. A 10-inch line running north and south on 23rd Avenue will connect into this 10-inch main at Lincoln and 23rd and with the 30-inch main on Nevin, at 23rd Avenue. There will be a 10-inch pipe on Garvin Avenue, connecting into the 10-inch main on 23rd Avenue at the west end and into the 16-inch pipe on San Pablo Avenue, at the east end. This completes the main skeleton of the system covering the northeast section of the city. Of the subdivisions laid out east of San Pablo Avenue, much of the territory lies at higher elevations and in a limited portion of it, a separate high level system will be necessary. The lower levels will be served by a system composed of loops off of the San Pablo Avenue and Alvarado Street lines.

On the west side there will be a 14-inch main connecting into the 36-inch line on Kearney Street about the middle of Walls Second Addition. This line will run westerly and southwesterly to the Schrock Furniture Company; thence along Gray Avenue and Hensley Street across to the Santa Fe Railway and down the Railway and Second Street to Nevin Avenue, connecting with a 16-inch line, which will run along Nevin Avenue from 6th to 1st Streets. A 12-inch line will connect into the 16-inch at Nevin Avenue and 1st Street, and connect into the line from the balancing reservoir at the angle point in the 24-inch line at Cutting Boulevard and Wine Avenue. The last block of this line will be a 20-inch main and will form a part of the 20-inch pipe which will extend from Cutting Boulevard and Wine Avenue along Standard Avenue and County Road No. 22, past the Standard Oil works and out to Winehaven.

On First Street there will be a 10-inch line, running south from the 16-inch main on Nevin Avenue. At Ohio Street the 10-inch pipe will end and connect into branch mains of smaller sizes. A similar short length of 10-inch pipe will connect into the 24-inch line on Nevin Avenue at 12th Street. This pipe will extend south on 12th to Ohio Street, and there connect into a network of smaller mains.

On Cutting Boulevard, a direct tie of 16-inch pipe will be made between the 24-inch main on 6th Street and the 12-inch main on Railroad Avenue. The 12-inch main on Railroad Avenue will turn at 23rd Avenue and will connect into the 30-inch main at Nevin and 23rd Avenues. It will connect into the 16-inch main from the west on Cutting Boulevard, and into the 18-inch main from the east on Potrero Avenue. It will continue as a 12-inch main on Railroad Avenue southeasterly from Potrero Avenue, and along the same general direction through Richmond Annex, following Columbia Boulevard to Coalinga Boulevard, along Coalinga to San Joaquin Avenue and along San Joaquin Avenue to Central Avenue. There it will turn east and continuing as a 12-inch pipe will run along Central Avenue to San Pablo Avenue, where it will connect into a 20-inch main on San Pablo.

A 12-inch loop will enclose a compact block of territory composed of the following subdivisions south of Cutting Boulevard and east of 23rd Avenue: El Cerrito Terrace, City of Pullman, El Cerrito Land Company, Pullman Center, Syndicate Business Blocks, Owens Addition, Seaver Addition, Syndicate Tract, Harbor Business Blocks and Harbor Gate. This loop will follow the street nearest the extreme west, south and east edge of the block of subdivisions named. It will be a 12-inch main throughout its entire length, and will connect into the 16-inch main on Cutting Boulevard at 23rd Avenue, and into the 18-inch main on Potrero at its west end at Railroad Avenue. Thus these subdivisions with the complete development of the system will be completely surrounded by large pipes and thus adequate pressures will be maintained throughout the network of smaller mains in the interior.

On San Pablo Avenue a 24-inch main will connect into the 30-inch main leading down from the reservoir and run along San Pablo to Potrero Avenue, where an 18-inch main will lead off on Potrero and a 20-inch main extend on down San Pablo to Central Avenue. At the latter point a 12-inch main will branch off on Central Avenue. On Potrero Avenue an 18-inch main will extend from San Pablo Avenue to Railroad Avenue. At the west end it will connect with and act as a feeder for three 12-inch mains running in three directions. At the east end it will connect into the 24-inch main on San Pablo Avenue.

Sizes of Laterals.

The following Tables Nos. 41 and 42 show for the immediate and ultimate distribution system the total length of each size of pipe proper and the proportion which the length of each size bears to the total length. These tables are comparable to Table No. 22 of Chapter III, which gives similar data for the present system of the Peoples Water Company in Richmond.

Table No. 41—Sizes of Pipe in Immediate Distribution System.

Size.	Length, Feet.	Percent of Total.	Percent of Total this Size and Smaller.
2	97,000	24.72	24.72
3	2,040	.52	25.24
4	69,000	17.59	42.83
6	71,000	18.11	60.94
8	61,400	15.66	76.60
10	10,900	2.78	79.38
12	7,550	1.93	81.31
14	8,160	2.08	83.39
16	6,560	1.67	85.06
18	5,100	1.30	86.36
20	24,170	6.15	92.51
24	17,650	4.50	97.01
30	11,740	2.99	100.00
Total.....	392,270	100.00	

Area served, 2,300 acres.
Average length of pipe per acre = 170 feet.

Table No. 42—Sizes of Pipe in Ultimate Distribution System.

Size	Length feet	Percentage of total length	Percentage of total this size and smaller
2	473,690	36.17	36.17
3	8,770	.67	36.84
4	236,950	18.20	55.04
6	282,800	21.61	76.65
8	149,020	11.38	88.03
10	34,640	2.65	90.68
12	36,110	2.76	93.44
14	8,160	.62	94.06
16	15,100	1.15	95.21
18	5,100	.39	95.60
20	24,170	1.85	97.45
24	21,650	1.65	99.10
30	11,740	.90	100.00
Total	1,307,900 feet	100.00	

Area served, 6,250 acres.
Average length of pipe per acre = 209 feet.

PIPE AND SPECIALS.

Kind.

It will be recommended that all large mains, that is, those of 18-inch diameter and larger, will be of either wood stave, of riveted steel, or of standard pattern cast iron. All of the smaller mains, excepting the 2-inch, and possibly the 4-inch, will be of standard bell and spigot pattern cast iron pipe. The 2-inch and possibly the 4-inch pipe will be galvanized wrought iron pipe, with screw connections.

Pressures.

The extreme range of pressures throughout the system will vary from 0 to 250 feet of head, or 0 to 108½ pounds per square inch. Throughout the major part of the system the static pressure will vary from 80 pounds to 100 pounds per square inch, equivalent to 185 to 230 feet head.

The following table shows the computed net head and net pressure with the system in full operation at its ultimate capacity, and at the time of maximum draft, including maximum fire draft. As previously explained, this is with the distribution system operating at the rate of 27,000,000 gallons per day.

Table No. 43—Pressures—Ultimate System—Ultimate Use.

Location	Net head feet	Net Pressures pounds
San Pablo and Macdonald	145	62
Macdonald and 23rd Street	165	71
Macdonald and 6th Street	172	74
Cutting and 6th Street	223	97
Cutting and Wine	240	103
Potrero at S. P. R. R.	175	75
San Pablo near County Line	145	62
San Pablo and Lincoln Avenue	113	48
Lincoln and 23rd Street	113	48
Kearney Street near San Pablo Station	123	53
San Pablo and Potrero	164	72
Ohio Street and 14th Street	137	59
Pennsylvania and 8th Street	130	56
Garvin Avenue half way between 23rd and San Pablo	135	58
Wall Street half way between Cutting and Macdonald	146	63
Garvin and 19th	116	50
Santa Fe and Richmond Avenue	187	81
Herman and 16th	186	81
Center of Boulevard Gardens No. 1	101	43

Life.

In calculating depreciation in order to determine the fixed charges for water, the life of cast iron pipe has been assumed as 80 years, that of riveted steel as 40 years, and that of wood stave as 20 years. The life of any water pipe in service depends upon so many factors, such as the quality of water, nature of the ground, care used in dipping and laying, stray electric currents, etc., that any estimate of its useful life is subject to much uncertainty. While that of any of the three kinds considered may vary within wide limits under different conditions, it is believed that the figures given above represent a fair average.

Specials.

This is the term applied to such pipe fittings as bends, junctions, T's, crosses, etc.

They will ordinarily be made of cast iron for all classes of pipe. On the small sizes saddle and screw connections can sometimes be used, but in general all junctions, changes of size, or abrupt changes of direction, will be made with cast iron specials.

Fire Hydrants.

Standard 2-way City Fire Hydrants will be installed throughout the system. A type should be selected which offers as little obstruction as possible to the free flow of water. They will be connected to the mains by 4-inch pipes in the residential section, and by 6-inch pipes in the business section.

Valves.

In the operation of a water system it is desirable at times to shut off portions of the system for making repairs or changes. It is also desirable in case of disastrous conflagration, when the best possible pressures are desired for fire protection, to shut off for a limited time, the mains leading to other parts of town not endangered, and use the entire resources of the water system in the district where the fire occurs.

The valves will be so placed that reasonably small sections of the system can be entirely shut off without interrupting the service in other sections. In general, valves will be placed on the small laterals at their junctions with the mains; and valves will be placed on the smaller mains at their junctions with the larger mains. Nearly all laterals receive water from mains at both ends. It will hence be possible to shut off the supply at either end and still maintain in the laterals, by the feed from the other end, pressure somewhat diminished, although probably sufficient for ordinary purposes. This point is very essential; and much annoyance of operation can be avoided by making a liberal allowance for valves.

WEST RICHMOND HIGH PRESSURE FIRE PROTECTION SYSTEM.

Reasons for System.

At West Richmond there are many valuable improvements in the Potrero Hills, which are too high to receive the most efficient gravity fire protection from the level of the distributing and balancing reservoirs. The immediate construction of harbor improvements in this vicinity will undoubtedly mean a more extended improved district on the hills, with buildings steadily increasing in number and value. It has accordingly been deemed desirable to design a separate high pressure fire system for this section. The area to be served is so limited that it is undesirable to design the entire system to accommodate it.

Extent of System.

If it is desired to comply with the requirements of the Underwriters for the lowest insurance rates, a minimum hydrant pressure of 80 pounds should be maintained. If the distributing reservoirs alone were depended on for this, the pressures would be up to the requirement only in the territory lying below about the 60-foot contour. At any points higher than 60 feet, the hydrant pressures would be correspondingly less. The 60-foot contour cuts Washington Avenue about Nicholl Avenue, and Tewksbury Avenue about at San Pablo Street. All of the territory south of Tewksbury from San Pablo Street west, and all that south of Scenic Avenue and Buena Vista Avenue lies above the 60-foot elevation, and cannot be furnished the required protection from the main reservoirs.

The area which the proposed high pressure system is designed to cover, together with the detailed size and location of the pipes and hydrants is shown on the aecompanying Plate No. 12.

The high pressure system, unless extended to lower levels as suggested below, will consist of a single 10-inch pipe along the top of the ridge of the Potrero Hills, with 6-inch branches to the fire hydrants, nearly all of which will be within 500 feet of the main line. As the territory along the top of the ridge develops, it will become necessary to lay a few small pipes for domestic service. On the higher levels these can be connected with the high pressure system. This applies especially to the higher streets of Marine View Terrace and Marine View Terrace Extension.

If thought advisable at any time, this system can be extended, at a comparatively small additional cost, to furnish very efficient additional fire protection for the highly improved business property on the lower levels, as along lower Washington, Richmond, Standard and Railroad Avenues. If the high pressure system were extended to this portion, it would be connected to the fire hydrants only, all other service being made from the low pressure mains. It would be possible in this way to maintain hydrant pressures along lower Washington Avenue of 140 pounds to 155 pounds per square inch. This extension will hardly be necessary until high buildings are constructed in the district described.

Interconnections With Main System.

The only connection necessary between the high pressure system and the main system will be through the pump, which raises water from the main system into the high pressure standpipe. If the mains of the high pressure system are not carried down to fire hydrants on the lower levels of this part of town, it would be well to put in a single connection, centrally located between the high pressure main and one of those of the other system. This could be arranged with a gate valve which would ordinarily remain closed. In case of fire or other excessive draft on the lower system, the gate valve could be opened and water at increased pressure let into the lower mains for a limited time.

Pressures.

The hydrant pressures in feet, head, and in pounds per square inch at the principal corners, with the system operated at its full capacity as specified below, have been compiled and are shown in the table on Plate 12, ranging from 78 to 117 pounds per square inch.

AUXILIARY RESERVOIR.

Location.

The most suitable site for the reservoir is on the hill at the head of Buena Vista Avenue about 1100 feet easterly from the south portal of the Santa Fe tunnel. The ground elevation on this hill is 360 to 370 feet. It is proposed to excavate the reservoir on the highest point of this hill. This elevation will give a net working pressure at the extreme end of the main line during periods of maximum draft of about 85½ pounds per square inch. This applies to the hydrant at Golden Gate Avenue, and McKinley Street. At points nearer the standpipe the pressures will be somewhat better, depending largely on the elevation of the point in question.

Capacity.

This system is primarily for fire protection on the higher levels although it will also serve to a limited extent for domestic use. The most important requirement of the standpipe as regards capacity is to furnish enough to suffice through the most severe fire. It is estimated that the maximum requirement for this purpose will be four 200 gallons per minute streams flowing continuously for six hours, and that at the end of this time, it will be permissible for the reservoir to be empty. It can be assumed that the pump will be started at the same time that the maximum draft begins and that it will replenish the standpipe at a rate equal to half that at which water is taken from it. Thus, if the standpipe is made of sufficient capacity to furnish the maximum number of streams for 4 hours, it is assumed that the pump will, during that time, have raised enough more water to supply an additional 2 hours. This is a rational assumption and the capacity of the reservoir has been estimated on a 4 hour basis as being 192,000 gallons for fire protection. The maximum requirement for domestic use from this system is estimated at 50 gallons per minute, Adding this for 6 hours gives a total required capacity for the reservoir of about 250,000 gallons.

Design.

Alternate cost estimates were made to determine which is most economical, a steel standpipe 45 feet in diameter and 23 feet 6 inches high, designed to hold 22 feet 6 inches of water, or a reinforced concrete lined reservoir excavated in the ground. The concrete lined reservoir to be circular, 65 feet in diameter, and 12 feet deep, designed to hold 10 feet of water. The concrete lined reservoir appears to be more economical and suitable and is hence adopted.

The general features of the design are shown on Plate No. 12. It will be excavated chiefly out of rock with rock embankment and a concrete lining. The 10-inch main will be led directly into the reservoir and will be fitted with a check valve conveniently located. The profile of the main pipe line is shown on Plate No. 12.

PUMPING PLANT.

Automatic Operation.

The pump will be operated by an electric motor which will be automatically controlled by a float so arranged that when the water in the reservoir falls below a certain level the pump will start and when the reservoir is full the pump will stop. This range of level in the reservoir ought not to be more than about two or three feet.

For a 65-foot diameter this is equivalent to about 50,000 gallons and with a pump of the capacity proposed would be furnished by pumping continuously for not more than 2½ hours, provided the system were under only the ordinary draft. This amount of water would ordinarily be sufficient for the day's use and the pump therefore would operate for 2 to 2½ hours each day.

Capacity.

The capacity of the pumping plant is so fixed by the arbitrary fire requirement that it shall be capable of entirely filling the reservoir by

continuously pumping for twelve hours. The maximum domestic draft of 50 gallons per minute was added to the capacity thus computed. On this basis the pump needs a capacity of 400 gallons per minute against a head of about 120 feet.

Cost of Pumping.

The pump when operating at full capacity will require about 25 horsepower. It will operate under ordinary conditions for about 2 to 2½ hours each day. Estimating on the latter figure as conservative, and taking ¾c. per hour per horsepower as the cost of electric power, gives an average cost of operation of 47c. per day or about $170 per year for power. Supervision has not been included, because it is assumed that it will be given by water department employees who would be necessary in any case.

For completely filling the reservoir the cost for power would be about $2.25, but this would be necessary only in cases of a very large and disastrous fire or on occasion when the reservoir is emptied for cleaning or repairs.

USABLE PORTIONS OF OLD DISTRIBUTION SYSTEMS.

The distribution systems of the existing water companies now in operation in Richmond are described in detail in Chapter III and are shown on Plate No. 2.

The pipes are generally too small to be able to furnish proper fire protection and in many cases too small even for the requirements of domestic use.

Of the existing systems that of the Peoples Water Company is by far the most extensive, and is the best designed to furnish adequate pressures. The pipes through the business center are mostly 2-inch and 4-inch in diameter. On Macdonald Avenue, there is a 12½-inch main running toward Point Richmond as far as 10th Street; thence down 10th to Ohio, and west on Ohio. There is a 6-inch main running west on Macdonald Avenue from 10th to 1st Street and another one north on 10th Street as far as Pennsylvania. In other portions of the city the existing pipes could be used as a part of the distribution system for domestic consumption. New mains, however, would have to be laid in the principal streets to give adequate fire protection.

In the other water systems there are no large mains. A portion of the pipes could, if desired, be used for domestic distribution requiring new installations in the residence sections for mains 6 inches and larger, to give fire protection.

West Richmond System.

The portion of the existing water systems that could be incorporated to the best advantage in the proposed new system is that portion of the system of the Peoples Water Company which covers the old town of Point Richmond. The reservoir on the hill has a capacity of 1,000,000 gallons and is at an elevation of 200 feet. If it were acquired with the system of pipes connected with it, domestic service could be furnished from it to West Richmond. Fire protection could then be furnished by extending the high pressure system. The present reservoir could then

act as a substitute for the proposed west side balancing reservoir as called for in these plans and the pipe line from the other reservoir would be made smaller. Since this reservoir would be lower by 50 feet than the one across town, it would be permissible to lose 50 feet of head in the pipe line and hence to make the pipe considerably smaller. The reservoir would be connected so that its supply would flow into the system only as the pressure there became less than that furnished by the reservoir. The saving in the west side reservoir and the big pipe line running to it, and saving on the pipe lines bought from the Peoples Water Company (provided they can be bought cheaper than to install new ones) would form the chief inducement for this change of plans. An estimate has been made on the changes in pipe lines to effect this change in plans and in this the smaller pipes are included on the assumption that the price would not differ materially, whether they were bought from the water company in place or were installed new. In the former case some allowance should be made for depreciation and the district should figure that the difference in first cost should be placed in a sinking fund for removal.

This indicates a possible saving of $10,000 to $20,000. The saving by this change is small compared to the change it would make in the service. The pressures, except on the high fire pressure system, would be reduced by about 20 pounds per square inch. Although the pressures will be large enough for ordinary domestic consumption, for the class of development that exists and can be expected to extend over all the sections of town, the additional pressure is highly desirable. The extensions from the mains of the high pressure system to supply fire hydrants have been limited to the higher elevations and to a few prominent corners on the lower levels. The rest of the district, under the alternate plan, would either depend for fire protection on the 200-foot elevation reservoir or must go to additional expense to extend more lines from the high pressure main. The capacity of the reservoir, while probably sufficient for the present will soon be outgrown and will need enlargement.

Desirability of Acquiring Existing Distribution Systems.

The whole question of acquiring existing distribution systems should be deferred until the district is in a position to either acquire these systems or parallel them with new mains. If the usable portions of the old systems can be taken over at a figure attractive to the district there will be a considerable saving of time and annoyance otherwise caused by the tearing up of streets. When in operation the district would have an enormous advantage over competitors in having an ample supply of pure, soft water stored at a high elevation. This advantage should be so decisive that the existing companies would be willing to dispose of their plants to the district at a fair rate, and discontinue operations. The saving in cost to the district over the cost of laying new pipes should be equivalent to a fair estimate of depreciation on the old pipes acquired and hence should be put into a fund for renewal. If this were done no difference should be made in the estimated cost of the distribution system, whether old or new pipes were used in whole or in part.

CHAPTER No. IX.

Cost Estimates

GENERAL SEGREGATIONS.

General estimates are given in this Chapter for the cost of developing the project to its ultimate capacity of 12 million gallons per day, first, with water supplied by surface runoff from the San Pablo Creek, and second, with water pumped from the Sacramento River.

The first item is exclusive of the cost of land for the San Pablo reservoir and watershed, a matter so problematical that the writers do not feel justified in making any cost estimates.

It is not necessary to develop the system to its ultimate capacity at present. Six million gallons per day will suffice for a number of years. Accordingly estimates are finally given for the cost of developing the recommended Sacramento River supply so that it will furnish immediately 6 million gallons per day. Portions which are inconvenient or expensive to enlarge should have their ultimate capacity when first installed. Other important portions, however, can be gradually enlarged as the increasing consumption warrants. This last group of estimates for a water supply developed from the Sacramento River with the present capacity of six million gallons per day is the only one of immediate interest, and is the one upon which the present bond issue should be based.

The cost of completing the development of the proposed system is important in judging of the general merit of the scheme and in predicting probable future water rates. As the city grows, until the 12 million gallon per day capacity is inadequate, further enlargement, addition or renewals will be continuously made. One of the great advantages of the recommended source of supply is that there will always be sufficient water to enable the required additional supply to be obtained from this same source. A study of the surface runoff of the San Pablo and Pinole Creek watersheds was necessary before intelligent conclusions could be reached regarding the source most suitable from all standpoints. Preliminary investigations indicate that no other primary sources of supply have sufficient merit to warrant a detailed investigation of the costs.

The cost estimates will be given under the three following general segregations, or groups:

Group A—12 million gallons per day, ultimate project to develop and distribute water from surface runoff.

Group B—12 million gallons per day, ultimate project to develop and distribute water from the Sacramento and San Joaquin Rivers.

Group C—Present 6 million gallons per day project, to develop and distribute water from the Sacramento and San Joaquin Rivers.

UNIT PRICES.

The unit prices used in the following estimates are based on prices quoted in the fall of 1913 by local manufacturers. These are believed to be quite conservative throughout. As it is the universal experience

that in large projects of this nature many unforeseen contingencies arise during construction work, a general addition of 10 per cent. has been made to each item to cover such contingencies. Many of the items, especially those not intended for immediate construction, have not been designed in detail and hence the cost estimates are quite general.

PIPE LINE.

This is by far the largest single item of cost. Alternate estimates have been made for the use of wood stave, riveted steel, and cast iron pipe. Estimates in all cases are based on the use of first-class construction throughout with ample safety for the heads involved and with the best possible preservative coatings to insure the longest life practicable to obtain. All pipe, except for short trestles, is to be buried underground in order to protect it from injury, to prolong its life, and to keep the water cool. On the peat lands of Sherman Island, the pipe will probably be buried for one-half of its depth, and covered with the material excavated from the trench.

Wood Stave Pipe.

The estimate on wood stave pipe is based on the prices quoted by local manufacutrers for pipe built in the trench, but not including hauling, trenching and backfilling. A flat charge of $2.00 per ton for hauling materials from the cars to the site of the work, and $1.00 per lineal foot for trenching and backfilling was used.

Riveted Steel Pipe.

The estimated cost of the riveted steel pipe is based on local quotations for pipe to which has been added a flat charge of $4.00 per ton for hauling to the site of the work, and $1.00 per lineal foot for trenching and backfilling, and 75 cents per lineal foot for laying and connecting the joints.

Cast Iron Pipe.

The estimate for cast iron pipe is based on a cost of $32.00 per ton f.o.b. Richmond, for the pipe, to which has been added a cost of $4.00 per ton for switching local freight, handling and hauling to the work, $1.00 per lineal foot for trenching and backfilling and 25 cents per foot for laying and connecting the joints. A high figure was used for handling and hauling, because of the great weight of the 12-foot lengths of pipe. This weight ranges from 2⅓ tons to 3¼ tons per piece. It was assumed that special equipment would be required to load and unload these pieces.

FILTER PLANTS.

The cost of the filters is estimated from a careful study of the cost of similar works, and by making proper allowance for the effect of local conditions.

PUMPING PLANTS.

The cost estimates for the pumping plants have been based on the use of first-class construction throughout, with heavy concrete founda-

tions, and reinforced concrete superstructures. As the buildings for the pumping plants and filters will be about the only opportunity for structures of esthetic appearance it is believed that the architectural merit of the plant should be carefully considered, even though a slight additional expense is involved.

TUNNEL.

If the alternate location for the conduit from Martinez to Pinole is used, involving a 15,000-foot tunnel, this will undoubtedly prove the slowest portion of the work, and hence to expedite its construction as much as possible, estimates have been based on the construction of two shafts, about 300 feet in depth, so that work could proceed simultaneously from six headings. About two-thirds of the material excavated would then have to be raised this extra 300 feet, materially increasing the unit cost, but enabling the tunnel to be completed within a period of 8 to 12 months.

RIGHTS OF WAY.

This is always one of the most difficult items to estimate. Unit figures have been used which are much above the average value of the land. Much of the conduit will be located along County roads, where it is assumed that the rights of way can be obtained at nominal cost. Libberal figures have been allowed for land to be acquired for reservoirs, especially in the urban section of the City of Richmond.

GROUP A—12 MILLION GALLONS PER DAY ULTIMATE PROJECT TO DEVELOP AND DISTRIBUTE WATER FROM SURFACE RUNOFF.

A-1 San Pablo Dam and Reservoir.

Earth dam 132 feet high, with corewall	$837,750
Inlet tower and accessories	31,350
Outlet tunnel	18,000
Pipe outlet, valves, etc.	8,500
Spillway, wasteway, etc.	8,750
	$ 904,350
Add 10 per cent for contingencies	90,435
	$ 994,785
Add 6 per cent for engineering	59,687
Total cost	$1,054,472

A-2 Pressure Filters.

12 million gallons per day capacity	
Estimated at $12,500 per million gallons	$ 150,000
Add 10 per cent for contingencies	15,000
	$ 165,000
Add 6 per cent for engineering	9,900
Total cost	$ 174,900

A-3 Tunnel to Richmond.

15,500 linear feet at $16.50	$ 256,000
Add 10 per cent for contingencies	25,600
	$ 281,600
Add 6 per cent for engineering	16,900
Total cost	$ 298,500

A-4-W Distribution System.

Using wood stave pipe for large sizes.

Pipes 2 inches to 30 inches	$1,345,831
Hydrants	66,800
	$1,412,631
Add 10 per cent for contingencies	141,263
Add 6 per cent for engineering	93,233
Total cost	$1,647,127

A-4-S Distribution System.

Using riveted steel pipe for large sizes.

Pipes 2 inches to 30 inches	$1,397,939
Hydrants	66,800
	$1,464,739
Add 10 per cent for contingencies	146,474
	$1,611,213
Add 6 per cent for engineering	96,673
Total cost	$1,707,886

A-4-I Distribution System.

Using cast iron pipe for large sizes.

Pipes 2 inches to 30 inches	$1,580,819
Hydrants	66,800
	$1,647,619
Add 10 per cent for contingencies	164,762
	$1,812,391
Add 6 per cent for engineering	108,743
Total cost	$1,921,124

A-5 West Side Balancing Reservoir.

Excavation, lining, fittings, etc.	$ 13,500
Add 10 per cent for contingencies	1,350
	$ 14,850
Add 6 per cent for engineering	890
	$ 15,740

A-6 Potrero Heights High Pressure System.

Pipes 2 inches to 10 inches	$ 23,765
Hydrants	1,800
Reservoir and pumping plant	6,400
	$ 31,965
Add 10 per cent for contingencies	3,195
	$ 35,160
Add 6 per cent for engineering	2,110
Total cost	$ 37,270

Summary of Costs of San Pablo Source.

Using wood stave pipe for large sizes.

A-1 Reservoir complete	$1,054,472
A-2 Filters	174,900
A-3 Tunnel to Richmond	298,500
A-4-W Distribution system	1,647,127
A-5 West side balancing reservoir	15,740
A-6 Potrero high pressure system	37,270
Total cost (exclusive of rights of way and lands)	$3,228,009

Summary of Costs of San Pablo Source.

Using riveted steel pipe for large sizes.

A-1 Reservoir complete	$1,054,472
A-2 Filters	174,900
A-3 Tunnel to Richmond	298,500
A-4-S Distribution system	1,707,886
A-5 West side balancing reservoir	15,740
A-6 Potrero high pressure system	37,270
Total cost (exclusive of rights of way and lands)	$3,288,766

Summary of Costs of San Pablo Source.

Using cast iron pipe for large sizes.

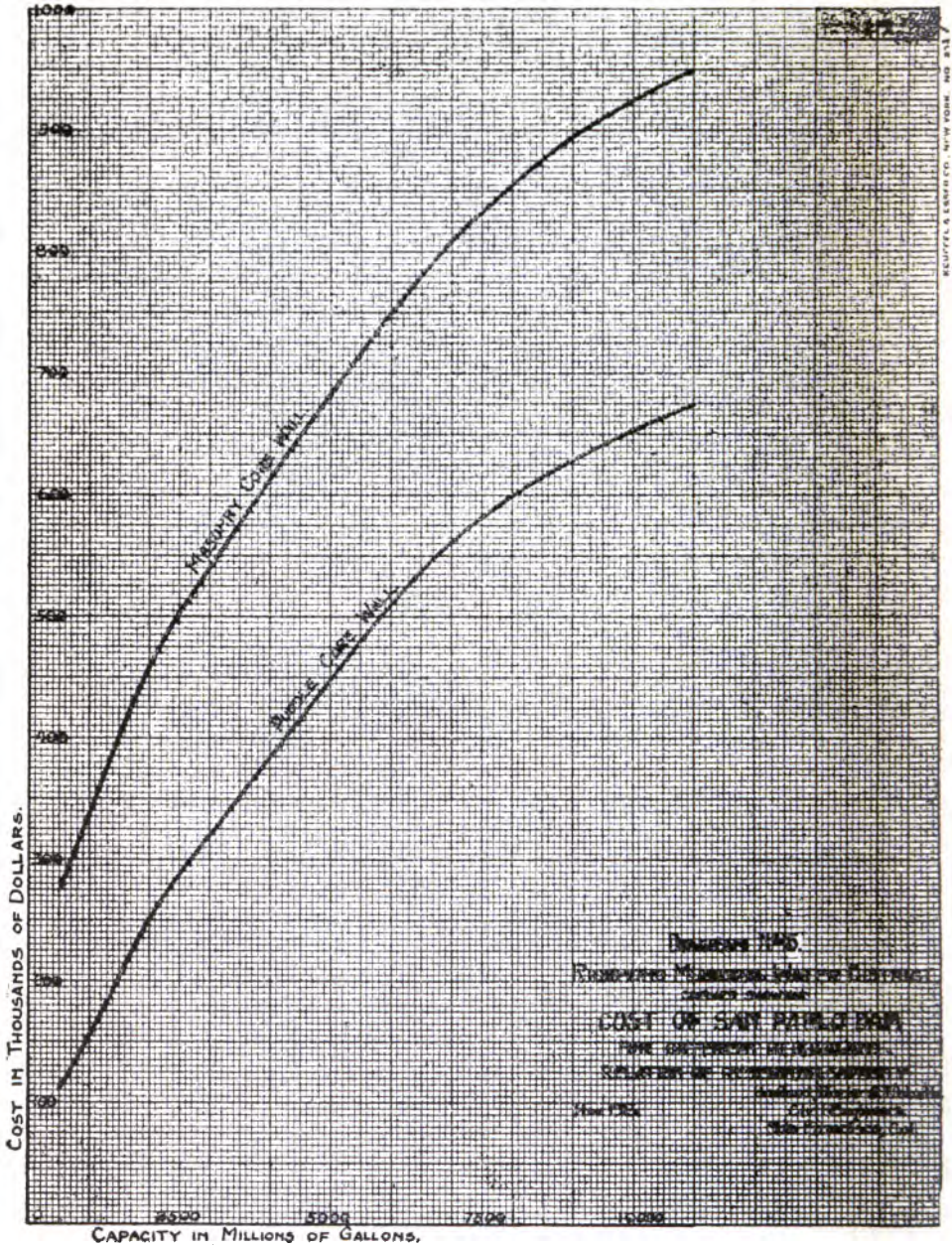
A-1 Reservoir complete	$1,054,472
A-2 Filters	174,900
A-3 Tunnel to Richmond	298,500
A-4-I Distribution system	1,921,124
A-5 West side balancing reservoir	15,740
A-6 Potrero high pressure system	37,270
Total cost (exclusive of rights of way and lands)	$3,502,006

Diagram No. 14 on the following page shows graphically the estimated cost of the San Pablo dam at heights sufficient to furnish different amounts of storage.

GROUP B—TO DEVELOP A SUPPLY OF 12 MILLION GALLONS FROM THE SACRAMENTO RIVER.

B-1 Pumping Plant at Toland's Landing.

Building, grading, foundations, etc	$ 5,400
Pile and timber wharf and support	4,500
Pipes, fittings, lifting derricks, etc.	1,500
Gasoline engine in place	7,000
2 14-inch 2-stage centrifugal pumps 2 10-inch 2-stage centrifugal pumps } in place complete	6,250
Motors, transformers, and electric equipment	10,000
	$ 34,650
Add 10 per cent for contingencies	3,465
	$ 38,115
Add 6 per cent for engineering	2,287
Total cost	$ 40,402


Masonry Core Wall
Rubble Core Wall
Cost in Thousands of Dollars.
Capacity in Millions of Gallons.

B-2 Conduit From Toland's Landing to Emergency Intake at Antioch

B-2-W Using wood stave pipe.

25,900 feet of 36-inch pipe (head 200-250 feet) complete in place	$127,140
3,430 linear feet 36-inch submarine crossings	80,000
Total, 29,330 feet	$207,140
Add 10 per cent for contingencies	20,714
	$227,854
Add 6 per cent for engineering	13,671
Total cost	$241,525

B-2-S Using riveted steel pipe.

25,900 feet of 36-inch pipe (head 200-250 feet) complete in place	$168,800
3,430 linear feet 36-inch submarine crossings	80,000
29,330 feet	$248,800
Add 10 per cent for contingencies	24,880
	$273,680
Add 6 per cent for engineering	16,421
Total cost	$290,101

B-2-I Using cast iron pipe.

25,900 feet of 36-inch pipe (head 200-250 feet) complete in place	$286,920
3,430 linear feet 36-inch submarine crossings	80,000
29,330 feet	$366,290
Add 10 per cent for contingencies	36,692
	$403,612
Add 6 per cent for engineering	24,217
Total cost	$427,829

B-3 Emergency Intake at Antioch.

Building, foundations, etc.	$ 5,400
Pile and timber wharf and pipe support	4,500
Pipes, fittings, lifting derrick, etc.	1,500
	$11,400
Add 10 per cent for contingencies	1,140
	$ 12,540
Add 6 per cent for engineering	760
Total cost	$ 13,300

B-4 Conduit From Emergency Intake at Antioch To Filters at Martinez.

B-4-W Using wood stave pipe.

114,300 feet 36-inch pipe (head 0-200 feet) complete in place	$426,844
Add 10 per cent for contingencies	42,684
	$469,528
Add 6 per cent for engineering	28,172
Total cost	$479,700

B-4-S Using riveted steel pipe.

114,300 feet 36-inch pipe (head 0-250 feet) complete in place	$578,020
Add 10 per cent for contingencies	57,802
	$635,822
Add 6 per cent for engineering	38,149
Total cost	$673,971

B-4-I Using cast iron pipe.

114,300 feet 36-inch pipe (head 0-300 feet) complete in place	$1,100,850
Add 10 per cent for contingencies	110,085
	$1,210,935
Add 6 per cent for engineering	72,656
Total cost	$1,283,591

B-5 Filter Plant at Martinez—Capacity 12 Million Gallons Per Day.

12 million gallons capacity at $12,500 per million gallons	$150,000
Add 10 per cent for contingencies	15,000
	$165,000
Add 6 per cent for engineering	9,900
Total cost	$174,900

B-6 Booster Pumping Plant at Martinez.

Building, gradings, foundations, etc.	$ 5,400
Gasoline engine in place	7,000
2 14-inch 2-stage centrifugal pumps } in place	6,250
2 10-inch 2-stage centrifugal pumps }	
Pipes, fittings, derrick, etc.	1,350
Motors, transformers and electric equipment	10,000
	$ 30,000
Add 10 per cent for contingencies	3,000
	$ 33,000
Add 6 per cent for engineering	1,980
Total cost	$ 34,980

B-7 CONDUIT FROM BOOSTER PUMPS AT MARTINEZ TO MARTINEZ RESERVOIR.

If the shore route is followed beyond Martinez reservoir, the pressure on this section will be somewhat larger than if the inland route is followed, due to the smaller friction loss in the latter case. This estimate (B-7) applies only in case the inland route is followed. For B-7, used with the shore route, the estimate has been combined with that of B-9 and is given complete from Martinez booster pumps to Richmond.

Following Inland Route.

B-7-W-I Using wood stave pipe.

9,520 feet 36-inch pipe (head 100-300 feet) complete in place	$ 45,370
Add 10 per cent for contingencies	4,537
	$ 49,907
Add 6 per cent for engineering	2,994
Total cost	$ 52,901

B-7-S-I Using riveted steel pipe.

9,520 feet 36-inch pipe (head 100-300 feet) complete in place	$ 58,946
Add 10 per cent for contingencies	5,895
	$ 64,841
Add 6 per cent for engineering	3,890
Total cost	$ 68,731

B-7-I-I Using cast iron pipe.

9,520 feet 36-inch (head 100-300 feet) complete in place	$102,656
Add 10 per cent for contingencies	10,266
	$112,922
Add 6 per cent for engineering	6,775
Total cost	$119,697

B-8 Martinez Reservoir.

Embankment and excavation for dam and spillway	$104,640
Concrete facing on water side of dam	10,000
Reinforced concrete spillway culverts, etc.	5,760
Reinforced concrete intake tower complete with valves and bridge	4,700
Clearing reservoir site	525
	$125,625
Add 10 per cent for contingencies	12,563
	$138,188
Add 6 per cent for engineering	8,291
Total cost	$146,479

Unit Prices Used in Making Above Estimate B-8.

Excavation.

In earth	$ .30 per cubic yard
In rock	1.00 per cubic yard
Embankment in dam	.50 per cubic yard

Concrete

Slope facing for dam	$ .25 per square foot
Reinforced spillway, culverts, etc.	12.00 per cubic yard
Reinforced concrete intake tower	20.00 per cubic yard
Plain in tower base	10.00 per cubic yard
Clearing land @	35.00 per acre

B-7 and B-9 CONDUIT FROM BOOSTER PUMPS TO RICHMOND FOLLOWING SHORE ROUTE.

B-7-W-S and B-9-W-S Shore Route Using Wood Stave Pipe.

100,300 feet 36-inch pipe (head 0-350 feet) complete in place	$558,784
Add 10 per cent for contingencies	55,878
	$614,662
Add 6 per cent for engineering	36,880
	$651,542

B-7-S-S and B-9-S-S Shore Route Using Riveted Steel Pipe.

100,300 feet 36-inch pipe (head 0-400 feet) complete in place	$698,888
Add 10 per cent for contingencies	69,889
	$768,777
Add 6 per cent for engineering	46,127
	$814,904

B-7-I-S and B-9-I-S Shore Route Using Cast-Iron Pipe.

100,300 feet 36-inch pipe (head 0-400 feet) complete in place	$1,193,302
Add 10 per cent for contingencies	119,330
	$1,312,632
Add 6 per cent for engineering	78,758
	$1,391,390

B-9 INLAND ROUTE INCLUDING TUNNEL.

B-9-W-I Using Wood Stave Pipe.

66,260 feet 36-inch pipe (head 0-300 feet) complete in place	$310,104
15,000 linear feet tunnel at $16.50 complete	247,500
	$557,604
Add 10 per cent for contingencies	55,760
	$613,364
Add 6 per cent for engineering	36,802
	$650,166

B-9-S-I Inland Route Using Riveted Steel Pipe From Martinez Reservoir to Richmond.

66,260 feet 36-inch pipe (head 0-300 feet) complete in place	$378,864
15,000 linear feet tunnel at $16.50 complete	247,500
	$626,364
Add 10 per cent for contingencies	62,636
	$689,000
Add 6 per cent for engineering	41,340
	$730,340

B-9-I-I Inland Route Using Cast Iron Pipe From Martinez Reservoir to Richmond.

66,260 feet 36-inch pipe (head 0-300 feet) complete in place	$ 712,170
15,000 linear feet tunnel at $16.50 complete	247,500
	$ 959,670
Add 10 per cent for contingencies	95,967
	$1,055,637
Add 6 per cent for engineering	63,338
	$1,118,975

For convenience in making comparison, the total costs of the conduit for the two alternate routes and for the three materials are herewith listed:

Conduit Using Shore Route and Wood Stave Pipe.

B-2-W	29,330 feet	$ 241,525
B-4-W	114,300 feet	497,700
B-7-W-S and B-9-W-S	100,300 feet	651,542
	x243,930 feet	*$1,390,767

xOr 46 miles.
*Or $5.71 per foot average cost, or $30,200 per mile.

Conduit Using Shore Route and Riveted Steel Pipe.

B-2-S	29,330 feet	$ 290,101
B-4-S	114,300 feet	673,971
B-7-S-S and B-9-S-S	100,300 feet	814,904
	x243,930 feet	*$1,778,976

xOr 46 miles.
*Or $7.30 per foot, or $38,700 per mile.

Conduit Using Shore Route and Cast Iron Pipe.

B-2-I	29,330 feet	$ 427,829
B-4-I	114,300 feet	1,283,591
B-7-I-S and B-9-I-S	100,300 feet	1,391,390
	x243,930 feet	*$3,102,810

xOr 46 miles.
*Or $12.70 per foot, or $67,500 per mile.

Conduit Using Inland Route and Wood Stave Pipe.

B-2-W	29,330 feet	$ 241,525
B-4-W	114,300 feet	497,700
B-7-W-I	9,520 feet	52,901
B-9-W-I	81,260 feet	650,166
	x234,410 feet	*$1,442,292

xOr 44.3 miles.
*Or $6.15 per foot, or $32,500 per mile.

Conduit Using Inland Route and Riveted Steel Pipe Including Tunnel.

B-2-S	29,330 feet	$ 290,101
B-4-S	114,300 feet	673,971
B-7-S-I	9,520 feet	68,731
B-9-S-I	81,260 feet	730,340
	x234,410 feet	*$1,763,143

xOr 44.3 miles.
*Or $7.53 per foot, or $39,800 per mile.

Conduit Using Inland Route and Cast Iron Pipe Including Tunnel.

B-2-I	29,330 feet	$ 427,829
B-4-I	114,300 feet	1,283,591
B-7-I-I	9,520 feet	119,697
B-9-I-I	81,260 feet	1,118,975
	x234,410 feet	*$2,950,092

xOr 44.3 miles.
*Or $12.58 per foot, or $66,500 per mile.

B-10 Main Distributing Reservoir at Richmond Junction Heights—Ultimate Capacity 90 Million Gallons.

Earthwork—excavation and embankment	$203,250
Concrete lining	71,920
Gate tower, culverts, spillways, etc.	15,320
	$290,490
Add 10 per cent for contingencies	29,049
	$319,539
Add 6 per cent for engineering	19,172
	$338,711

B-11 West Side Balancing Reservoir.

Excavation and embankment	$ 9,900
Concrete lining	3,600
	$ 13,500
Add 10 per cent for contingencies	1,350
	$ 14,850
Add 6 per cent for engineering	890
	$ 15,740

B-12 Summary of Pipes in Ultimate Distribution System.

Size feet	Lenth	B-12-W Large mains w. s. unit cost	B-12-W Large mains w. s. total cost	B-12-S Large mains r. s. unit cost	B-12-S Large mains r. s. total cost	B-12-I Large mains c. i. unit cost	B-12-I Large mains c. i. total cost
2	473,690	$ .34	$161,050				
3	8,770	.53	4,650				
4	236,950	.77	182,450				
6	282,800	1.08	305,420				
8	149,020	1.50	223,530	Small sizes same for all systems			
10	34,640	2.15	74,480				
12	36,110	2.63	94,970				
14	8,160	3.24	26,440				
16	15,100	3.90 ci	58,890				
18	5,100	2.00 ws	10,200	2.70 rs	13,770	4.59 ci	23,410
20	24,170	2.25	54,380	2.95	71,300	5.61	135,590
24	21,650	2.70	58,460	3.50	75,780	7.03	152,200
30	11,740	3.25	38,160	4.38	51,420	9.99	117,283
1,250	hydrants at	$50.00	62,500		62,500		62,500
	1,307,900		$1,355,580				
Add 6% for engineering...			81,350		$1,406,650		$1,622,863
					84,400		97,372
Total cost			$1,436,930		$1,491,050		$1,720,235
Area served							6,250 acres
Cost per acre				$230.00	$239.00		$275.00
Average cost per lin. ft.....				1.00	1.14		1.31½

NOTE.—The unit prices used herein are large enough to cover the 10% allowed for contingencies in other portions of this report.

B-13 POTRERO HIGH PRESSURE FIRE PROTECTION SYSTEM —ULTIMATE SYSTEM.

Summary of Pipes and Hydrants.

Size.	Length.	Unit Cost.	Total Cost.	
2 inch	5,400 ft.	$0.34 p. l. f.	1,835	
6 "	6,500 "	1.08 "	7,020	
8 "	1,900 "	1.50 "	2,850	
10 "	5,600 "	2.15 "	12,040	
36 hydrants at $50.00			1,800	
				$25,545
Reservoir—				
Excavation			$4,510	
Lining, valves, etc.			1,316	
				5,826
Pumping plant and machinery				1,212
				$32,583
Add 6% for engineering				1,957
Total cost				$34,540

NOTE.—The unit prices used herein are large enough to cover the 10% allowed for contingencies in other portions of this report.

SUMMARY OF COST ESTIMATE FOR ULTIMATE SYSTEM— SHORE ROUTE—USING WOOD STAVE PIPE.

Item.	Construction Costs.	Land & Right of Way.	Total Cost.
B-1 Intake pumps	40,402	600	41,002
B-2-W conduit	241,525	7,200	248,725
B-3 Emergency intake	13,300	600	13,900
B-4-W Conduit	497,700	13,200	510,900
B-5 Filters	174,900		
B-6 Booster pumps	34,980	7,200	217,080
B-7-W-S and B-9-W-S Conduit	651,542	36,120	687,662
B-8 Martinez Reservoir	146,479	7,200	153,679
B-10 Dist. Reservoir	338,711	90,000	428.711
B-11 Bal. Reservoir	15,740	12,000	27,740
B-12-W Dist. System	1,436,930	.....	1,436,930
B-13 High Pres. System	34,540	3,000	37,540
Total	$3,626,742	$177,120	$3,803,862
If Inland Route is Used.			
	+51,525	—35,220	+16,305
Total	$3,678,267	$141,900	$3,820,167

SUMMARY OF COST ESTIMATES OF ULTIMATE SYSTEM— SHORE ROUTE—USING RIVETED STEEL PIPE.

Item.	Construction Costs.	Cost of Land & Right of Way.	Total Cost.
B-I Intake pumps	40,402	600	41,002
B-2-S Conduit	290,101	7,200	297,301
B-3 Emerg. Intake	13,300	600	13,900
B-4-S Conduit	673,971	13,200	687,171
B-5 Filters	174,900	7,200	217,080
B-6 Booster pumps	34,980		
B-7-S-S and B-9-S-S Conduit	814,904	36,120	851,024
B-8 Martinez Reservoir	146,479	7,200	153,679
B-10 Dist. Reservoir	338,711	90,000	428,711
B-11 Bal. Reservoir	15,740	12,000	27,740
B-12 Dist. System	1,491,050	.....	1,491,050
B-13 High Pres. System	34,540	3,000	37,540
Total cost	$4,069,078	$177,120	$4,246,198

If Inland Route is Used.

	—15,833	—35,220	—51,053
Total cost	$4,053,245	$141,900	$4,195,145

SUMMARY OF COST ESTIMATES FOR ULTIMATE SYSTEM—SHORE ROUTE—USING CAST-IRON PIPE.

Item.	Construction Costs.	Land & Right of Way.	Total Cost.
B-1 Intake pumps	$ 40,402	600	41,002
B-2-I Conduit	27,829	7,200	435,029
B-3 Emergency intake	13,300	600	13,900
B-4-I Conduit	1,283,591	13,200	1,296,791
B-5 Filters	174,900	7,200	217,080
B-6 Booster pumps	34,980		
B-7-I-S } B-9-I-S } conduit	1,391,390	36,120	1,427,510
B-8 Martinez reservoir	146,479	7,200	153,679
B-10 District reservoir	338,711	90,000	428,711
B-11 Bal. reservoir	15,740	12,000	27,740
B-12-I Dist. system	1,720,235	.....	1,720,235
B-13 High pressure system	34,540	3,000	37,540
Total cost	$5,622,097	$ 177,120	$5,799,217

If Inland Route Is Used.

	— 152,718	— 35,220	— 187,938
	$5,469,379	$ 141,900	$5,611,279

GROUP C—IMMEDIATE—TO DEVELOP A SUPPLY OF SIX MILLION GALLONS PER DAY FROM THE SACRAMENTO RIVER.

In this segregation only those items to be a part of the present project will be enumerated, and they will be given numbers corresponding to the notation in the preceding discussion of the ultimate scheme.

C-1—Intake and Pumping Plant at Tolands Landing

Building, grading foundations, etc.	$ 5,400
Pile and timber wharf and supports	4,500
Pipes, fittings, lifting derrick, etc.	1,500
Gasoline engine in place	7,000
1 14-inch 2-stage centrifugal pump } 2 10-inch 2-stage centrifugal pump }	4,200
Motors, transformers, elect. equipment	7,500
	$30,100
Add 10% for contingencies	3,010
	$33,110
Add 6% for engineering	2,000
Total cost	$35,110

C-2, C-3, and C-4 are the same as B-2, B-3 and B-4, discussed on previous pages and estimated to cost as follows:

C-2 Conduit From Intake to Emergency Intake.

C-2-W Using wood stave pipe	$ 241,525
C-2-S Using riveted steel pipe	290,101
C-2-I Using cast iron pipe	427,829

C-3 Emergency Intake at Antioch.

Same as B-3 (see page 161)	$ 13,300

C-4 Conduit From Emergency Intake to Booster Pumps at Martinez.

C-4-W Using wood stave pipe	$ 497,700
C-4-S Using riveted steel pipe	673,971
C-4-I Using cast iron pipe	1,283,591

C-5 Filter Plant at Martinez. Capacity 6 Million Gallons.

Complete with building—settling basin and appurtenances	$ 100,000
Add 10% for contingencies	10,000
	$110,000
Add 6% for engineering	6,600
Total cost	$ 116,600

C-6 Booster Pumps at Martinez.

Building, grading, foundations, etc	$ 5,400
Gasoline engine in place	7,000
One 14-inch 2-stage centrifugal pump; 2 10-inch 2-stage centrifugal pump	4,200
Motors, transformers, elect. equipment	7,500
Piping, fittings, lifting derrick, etc	1,350
	$ 25,450
Add 10% for contingencies	2,545
	$ 27,995
Add 6% for engineering	1,680
Total cost	$ 29,675

Pipe line same as under Segregation B.
C-7 and C-9 same as B-7 and B-9.
Martinez Reservoir not included.

C-10 Main Distribution Reservoir. Capacity 30 Million Gallons.

Excavation and embankment	$ 72,750
Concrete lining	34,573
Gate tower, spillway, etc.	8,875
	$116,198
Add 10% for contingencies	11,620
	$127,818
Add 6% for engineering	7,669
Total cost	$135,487

C-12 Summary of Pipes in Proposed Immediate Distributing System.

Size feet	Total Length	C-12-W Large mains w. s. unit cost	C-12-W Large mains w. s. total cost	C-12-S Large mains r. s. cost	C-12-S Large mains r. s. total cost	C-12-I Large mins c. i. unit cost	C-12-I Large mins c. i. total cost
2	97,000	$ .34	$32,980				
3	2,040	.53	1,080				
4	69,000	.77	53,130	Small sizes same for all systems			
6	71,000	1.08	76,680				
8	61,400	1.50	92,100				
10	10,900	2.15	23,430				
12	7,550	2.63	19,860				
14	8,160	3.24	26,440				
16	6,560 ci	3.90	25,590				
18	5,100 ws	2.00	10,200	2.70	13,750	4.59	23,400
20	24,170	2.25	54,380	2.95	71,250	5.61	135,500
24	17,650	2.70	47,655	3.50	61,800	7.03	124,000
30	11,740	3.25	38,155	4.38	51,500	8.12	95,300
238 hydrants at $50.00			11,900		11,900		11,900
Total, 392,270 feet.....					$513,580	$561,490	$741,390
Add 6% for engineering					30,815	33,690	44,480
Grand Total					$544,395	$595,180	$785,870
Area served							2,300 acres.
Cost per acre.....					$237	$259	$341

NOTE.—The unit prices used herein are large enough to cover the 10% allowed for contingencies in other portions of this report.

C-13 POTRERO HIGH PRESSURE FIRE PROTECTION SYSTEM —IMMEDIATE INSTALLATION.

Immediate System.

Size.	Length.	Unit Cost.	Total Cost.	
6 inch	4,600 ft.	$1.08 p. l. f.	$ 4,970	
8 "	1,900 "	1.50 "	2,850	
10 "	5,600 "	2.15 "	12,050	
33 hydrants at $50.00.....			1,650	
				$21,520
Reservoir—Excavation			$4,510	
Lining, valves, etc.			1,316	
				5,826
Pumping Plant and Machinery				1,212
				$28,558
Add 6% for engineering				1,712
Total cost				$30,270

NOTE.—The unit prices used herein are large enough to cover the 10% allowed for contingencies in other portions of this report.

SUMMARY OF COST ESTIMATES FOR IMMEDIATE SYSTEM—SHORE ROUTE USING WOOD STAVE PIPE.

Item.	Construction. Costs.	Land & Right of Way.	Total Cost.
C-1 Intake pumps	$ 35,110	600	$ 35,710
C-2-W Conduit	241,525	7,200	248,725
C-3 Emer. intake	13,300	600	13,900
C-4-W Conduit	497,700	13,200	510,900
C-5 Filters	116,600	7,200	153,475
C-6 Booster pumps	29,675		
C-7-W-S, C-9-W-S conduit	651,542	36,120	687,662
C-10 Dist. reservoir	135,487	90,000	225,487
C-12-W Dist. system	544,395	....	544,395
C-13 High pressure system	30,270	3,000	33,270
Total cost	$2,295,604	$157,920	$2,453,524
If inland route is used	+51,525	—35,220	+16,305
	$2,347,129	$122,700	$2,469,829

SUMMARY OF COST ESTIMATES FOR IMMEDIATE SYSTEM—SHORE ROUTE USING RIVETED STEEL PIPE.

Item.	Construction Costs.	Land & Right of Way.	Total Cost.
C-I Intake Pumps	$ 35,110	600	$ 35,710
C-2-S Conduit	290,101	7,200	297,301
C-3 Emer. Intake	13,300	600	13,900
C-4-S Conduit	673,971	13,200	687,171
C-5 Filters	116,600	7,200	153,475
C-6 Booster pumps	29,675		
C-7-S-S and C-9-S-S Conduit	814,904	36,120	851,024
C-10 Dist. Reservoir	135,487	90,000	225,487
C-12-W Dist. System	595,180	.....	595,180
C-13 High Pres. System	30,270	3,000	33,270
Total cost	$2,734,598	$157,920	$2,892,518
If inland route is used	+15,833	—35,220	—51,053
Total cost	$2,718,765	$122,700	$2,841,465

SUMMARY OF COST ESTIMATES FOR IMMEDIATE SYSTEM—SHORE ROUTE USING CAST-IRON PIPE.

Item.	Construction Costs.	Land & Right of Way.	Total Cost.
C-I Intake Pumps	$ 35,110	600	$ 35,710
C-2-I Conduit	427,829	7,200	435,029
C-3 Emer. Intake	13,300	600	13,900
C-4-I Conduit	1,283,591	13,200	1,296,791
C-5 Filters	116,600	7,200	153,475
C-6 Booster Pumps	29,675		
C-7-I-S and C-9-I-S Conduit	1,391,390	36,120	1,427,510
C-10 Dist. Reservoir	135,487	90,000	225,487
C-12-I Dist. System	785,870	.....	785,870
C-13 High Pres. System	30,270	3,000	33,270
Total cost	$4,249,122	$157,920	$4,407,042
Is inland route is used	—152,718	—35,220	—187,938
Total cost	$4,096,404	$122,700	$4,219,104

CHAPTER No. X.

Estimate of Operating Cost, Fixed Charges and Probable Water Rates Proposed Sacramento Supply

GENERAL STATEMENT.

In Chapter IV there is presented an extended statement of the water rates in effect in various California municipalities. In order that the financial merits of the proposed water supply may be correctly judged, it is desirable to estimate the probable cost of delivering water to the consumers at various periods in the life of the proposed system. The figures given in this chapter are based upon the estimated cost of the proposed Sacramento conduit built to deliver immediately an average of six million gallons per day (Group "C" of the preceding Chapter IX). As previously explained, the more costly portions of the proposed works are incapable of enlargement, and hence fixed charges must for the present be met on the cost of a project, the larger portion of which is not required for immediate use.

GENERAL METHODS OF ESTIMATING WATER RATES.

Two general methods are given herein as a basis for fixing water rates. The first method calculates fixed charges by assuming the life of each portion of the project and assuming that a certain amount will be laid aside each year, which, with accumulated interest, will furnish a fund sufficient to replace each portion of the project at the termination of its assumed life. The second method is designed to furnish sufficient funds to meet operating and administration expenses, interest on bond issue, and the retirement of a given amount of the principal of the bonds each year. When portions of the plan require renewal, funds should be obtained by the reissuance of bonds, and rates should be fixed so as to permit the accumulation of sufficient surplus so that such reissuance of bonds will not increase the total bonded indebtedness.

In either case, it should of course be evident that enlargements to the system should be made by additional or supplementary bond issues.

This estimate is based upon the items and costs given in Group "C" of Chapter IX for the recommended Sacramento River Supply. The assumed life of the essential features of the project is as follows:

Wood Stave Pipe	20 years.
Pumping Machinery, Etc.	20 "
Riveted Steel Pipe	40 "
Filters, Buildings, Etc.	60 "
Cast Iron Pipe	80 "

Reservoirs and rights of way, perpetual.

The depreciation charges on each of these items have been based on the assumption that the item would have to be renewed at the end of its assumed life. It has been assumed that an annual annuity will be laid aside of such an amount, that, with interest compounded annually at 5

per cent., it will give a fund sufficient for the replacement of the item under consideration. The interest charges have been based on the assumption of 5 per cent., and the operating charges for pumping and filtration have been based on a conservative estimate of the cost of operating the works as found by a study of the operating costs of similar works in other parts of the country. It has been assumed that a flat charge equal to about $50 per million gallons of water distributed would be due to administration, costs of operating the system as a whole, chiefly the distribution system, and this has been added to make up the final figure.

The figures for cost as estimated by this method are theoretical in that they provide no amortization fund and are based on the assumption that the bond issues will remain the same and that when additions or increase in capacity of any part of the system are necessary, a new bond issue will have to be made to cover their cost. In other words, it has been assumed that the interest on the bond issue will be perpetual, and that the charges will be such as are necessary to pay that interest, plus the operating expenses; and to provide for the renewal of the parts of the system as they become useless.

If we figure the charges for water to provide not only for depreciation of the parts of the system, but also for the retiring of the bonds, we are placing upon this system the burden not only of paying for itself, but also the burden of building a new system when this one has outlived its usefulness. This method of fixing rates would be obviously unfair to the consumers, in that they would be paying not only for their own benefits, but also for those of future generations as well, so if the rates are figured to provide money for retiring of the bonds they will not be figured high enough to also take care of depreciation, and the replacement of parts whose usefulness is past, must be made through the issuing of new bonds.

This is in accord with the stand that the Railroad Commissioners throughout the country have taken on questions of this kind when dealing with private corporations, and it is highly probable that the Richmond District would be compelled to conform to this general principle when fixing their own rates.

The detailed figures on the cost per million gallons, figured on the theoretical basis of interest and operation, plus depreciation charges for the different portions of the system are herewith given in the following Tables Nos. 44, 45 and 46, in which alternate estimates have been made for the three kinds of pipe proposed, and for the two alternate routes:

Table No. 44—Fixed Charges on Sacramento Filtered Water Supply, Interest, Operation, Depreciation, Using Wood Stave Pipe.

Item. Delivery.	Inland Route. 4 m. gallons per day.	6 m. gallons per day.	12 m. gallons per day.	Shore Route. 4 m. gallons per day.	6 m. gallons per day.	12 m. gallons per day.
1. Toland Pump plt.	$ 1.80	$1.21	$ .71	$ 1.80	$ 1.21	$ .71
2. Pipe Line	11.40	7.60	3.80	11.40	7.60	3.80
3. Emergcy Intake	.61	.41	.20	.61	.41	.20
4. Pipe Line	27.30	18.20	9.10	27.30	18.20	9.10
5. Filters	4.22	2.81	2.11	4.22	2.81	2.11
6. Booster Pump plt.	1.51	1.01	.60	1.51	1.01	.60
7. Pipe Line	2.90	1.94	.97	35.80	23.90	11.95
8. Martinez Resev. ..	....	....	1.66	.....	.....	1.66
9. Pipe Line.....	29.95	19.95	9.98	With No. 7		
10. Distrib. Resv.	4.64	3.09	3.87	4.64	3.09	3.87
11 Balancing Reserv..	....	....	.18	....	....	.18
12 Distributing Sys..	22.25	14.80	17.90	22.25	14.80	17.90
13 High Pressure Sys	1.08	.72	.41	1.08	.72	.41
Rights of Way.....	4.85	3.24	1.62	6.07	4.05	2.02
Pumping	14.10	15.30	21.95	14.30	15.70	23.20
Filtration	10.00	10.00	10.00	10.00	10.00	10.00
Administration	50.00	50.00	50.00	50.00	50.00	50.00
Total cost per M. G..	$186.61	$150.29	$135.06	$190.98	$153.50	$137.71
Cost per 1,000 gal....	18¾c	15c	13½c	19c	15½c	13¾c

Table No. 45—Fixed Charges on Sacramento Filtered Water Supply, Interest, Operation, Depreciation, Using Riveted Steel Pipe.

Item. Delivery.	Inland Route. 4 m. gallons per day.	6 m. gallons per day.	12 m. gallons per day.	Shore Route. 4 m. gallons per day.	6 m. gallons per day.	12 m. gallons per day.
1 Toland Pump plant	$1.80	$1.21	$0.71	$1.80	$1.21	$0.71
2 Pipe Line	11.10	7.41	3.70	11.10	7.41	3.70
3 Emergency Intake.	.61	.41	.20	.61	.41	.20
4 Pipe Line	26.90	17.90	8.95	26.90	17.90	8.95
5 Filters	4.22	2.81	2.11	4.22	2.81	2.11
6 Booster Pump Plnt	1.51	1.01	.60	1.51	1.01	.60
7 Pipe Line	2.75	1.83	.92	32.50	21.70	10.85
8 Martinez Resvoir..	....	....	1.66			
9 Pipe Line	27.75	18.45	9.23	....	....	1.66
10 Distrib. Reservoir..	4.64	3.09	3.87	4.64	3.09	3.87
11 Balancing Reserv.	....	....	.18	....	....	.18
12 Distribution Sys..	21.85	14.55	17.75	21.85	14.55	17.75
13 High Pressure Sys.	1.08	.72	.41	1.08	.72	.41
Rights of Way	4.85	3.24	1.62	6.07	4.05	2.02
Pumping	14.65	16.50	26.30	14.90	17.00	28.20
Filtration	10.00	10.00	10.00	10.00	10.00	10.00
Administration	50.00	50.00	50.00	50.00	50.00	50.00
Total cost per M. G...	$183.71	$149.13	$138.21	$187.18	$151.86	$141.21
Cost per 1,000 gallons.	18½	15	14	18¾	15¼	14¼

Table No. 46—Fixed Charges on Sacramento Filtered Water Supply, Interest, Operation, Depreciation, Using Cast Iron Pipe.

Item. Delivery.	Inland Route. 4 m. gallons per day.	Inland Route. 6 m. gallons per day.	Inland Route. 12 m. gallons per day.	Shore Route. 4 m. gallons per day.	Shore Route. 6 m. gallons per day.	Shore Route. 12 m. gallons per day.
1 Toland Pump. Plant	$1.80	$1.21	$0.71	$1.80	$1.21	$0.71
2 Pipe Line	14.95	9.98	4.99	14.95	9.98	4.99
3 Emergency Intake.	.61	.41	.20	.61	.41	.20
4 Pipe Line	44.80	29.90	14.95	44.80	29.90	14.95
5 Filters	4.22	2.81	2.11	4.22	2.81	2.11
6 Booster Pump Plant	1.51	1.01	.60	1.51	1.01	.60
7 Pipe Line	4.18	2.79	1.39	48.75	32.50	16.25
9 Pipe Line	39.10	26.05	13.03	....	....	....
8 Martinez Reservoir	....	....	1.66	....	....	1.66
10 Distribution Resv..	4.64	3.09	3.87	4.64	3.09	3.87
11 Balancing Reserv'r	....	....	.18	....	....	.18
12 Distrib. System...	27.45	18.30	20.05	27.45	18.30	20.05
13 High Pressure Sys.	1.08	.72	.41	1.08	.72	.41
Rights of Way	4.85	3.24	1.62	6.07	4.05	2.02
Pumping	14.60	16.10	25.10	14.80	16.60	26.80
Filtration	10.00	10.00	10.00	10.00	10.00	10.00
Administration	50.00	50.00	50.00	50.00	50.00	50.00
Total cost per M. G...	$223.79	$175.61	$150.87	$230.68	$180.58	$154.80
Cost per 1,000 gallons..	22½	17½	15	23	18	15½

It will be seen that the average costs using wood stave and riveted steel pipe are practically identical. The average cost of the cast iron pipe is somewhat greater, especially where its full capacity is not used.

Estimate of Rates to Provide for Bond Retirement.

The second method of fixing rates is to provide revenue that will furnish sufficient funds to meet operating and administration expenses, interest on the bond issue, and the retiring of a given amount of the principal of the bonds each year. An effort has been made to estimate a rate that will conform with the following requirements:

1. A bond issue furnishing for construction purposes $2,500,000 with interest at 5 per cent.

2. The rates on the water sold will take care of all costs in connection with the bond issue and operation of the system generally and cause no change in the tax rates in the District.

3. The rates for the first year shall provide for the payment of the interest, operation and a fund sufficient to retire one-fortieth of the entire bond issue.

4. Thereafter the rates shall be sufficient to retire annually one-fortieth of the principal in addition to paying the interest and operation costs.

5. Enough surplus shall be accumulated so that the system may be replaced as parts of it depreciate, by using this surplus and by the reissuance of bonds so as to keep the total bonded indebtedness at not more than $2,500,000; any enlargements and extensions to the system to be taken care of by the issuing of bonds in excess of the $2,500,000 limit, this excess, however, to take care of such extensions only, and all

costs for the portion of the system first installed to be provided by the rates and a total bond issue never in excess of $2,500,000.

6. That the rates per thousand gallons of water be gradually decreased until a fixed minimum is reached. In making an estimate of this decrease, the amount of water which will be sold has been based on the predictions of future population and consumption given in Tables 16 and 17 of Chapter II.

If the assumption is made that for the first year (1915) a total of four million gallons per day will be sold, it will need to be sold at an average rate of about 20 cents per thousand gallons, in order to cover all charges, including the retirement of one-fortieth of the bond issue. If a larger amount of water than this can be disposed of, the rates will be correspondingly decreased, and if the amount should reach a figure as high as 6 m.g.d., an average rate of only 16 cents to 18 cents per thousand gallons need be charged.

The detailed figures in this portion of the report are based on the estimate given of the cost of the system using wood stave pipe, but if based on the system with the riveted steel pipe as estimated in Chapter IX, the variation in the essential items would not be more than two or three per cent. Provided the total project could be brought within the proposed bond issue of two and one-half million dollars, the rates can be figured as essentially the same. If cast iron pipe is used for the conduit and distribution system, the fixed charges would be materially increased, and the rate necessary to be charged would probably somewhat exceed 30 cents per thousand gallons, or not much less than that now paid.

The amount to be paid the first year will be operation, interest, administration, bond installment, basis 4 m.g.d.

Operation (Filters, pumping)	$ 35,200
Interest—5 per cent on $2,500,000	125,000
Administration (assumed 5 cents per 1,000 gallons)	73,000
Bond installment one-fortieth of $2,500,000	62,500
Total charge	$295,700
Cost per million gallons	$202.00
Cost per thousand gallons	20.2c

The interest and bond installments will be constant until the plant has to be enlarged which will not be until the daily consumption exceeds 6 m.g.p.d. This will not be until about 1919. For water furnished at a rate of 6 m.g.d., the fixed charges are:

Operation (Filters, pumping)	$ 55,500
Interest—5 per cent on $2,500,000 (This neglects the reduction due to installments already paid)	125,000
Administration	109,500
Bond installments, one-fortieth of $2,500,000	62,500
Total annual charge for 6 million gallons daily	$352,500
Cost per million gallons	$161.00
Cost per thousand gallons	16.1c

If the average charge were kept up to 20 cents per thousand gallons, then during the year 1919, according to previous assumptions, a surplus of about $80,000 would be saved and during the preceding years, about one and one-half times this amount. Assuming 1915 as the first year of

operation, the surplus at the end of 1919 ought to be $200,000, from an average rate of 20 cents per thousand gallons for the first five years of operation. During the years 1920 and 1921 the pumping plants, filters and distribution system would be operating under an allowable overload. By 1922 the plant would certainly have to be enlarged, and this would be done by an additional bond issue. The cost of additions necessary at that time would be approximately:

Pumps and filter enlargements	$ 50,000
Reservoir enlargements	250,000
Distribution system additions	200,000
Total	$500,000

Say approximately half a million dollars.

An analyses of condition at that time, assuming a rate of 20 cents per thousand gallons had been maintained, gives the following results:

Surplus.

Including 1919, 1920 and 1921, 2 years average consumption, 6½ m. g. d.		$200,000
Costs—Interest on $2,187,500, 2 years at 5 per cent	$218,750	
Two installments of bond issue at $62,500	125,000	
Operation, 6½x365, $25.30	120,000	
Administration and distribution at 5 cents per mil. gal.	237,000	
Total	$700,750	
Receipts—Water at 20 cents equals 200x6½x365x2 years	$950,000	$249,250
Total surplus		$449,250

If the total cost of enlargement as given above is $500,000, and the total surplus of $449,250 is used for this purpose, there will still be a deficiency of about $50,000 to be met by a supplementary bond issue. Assume a reissue of 5 year 5 per cent. bonds.

By this time, however, seven installments will have been paid on the original bond issue amounting to a total of $437,500.

If the district rebonds for $50,000 using the accumulated surplus for the additional money, necessary for the additions, the total bonded indebtedness will be $400,000 less than it was at first.

Charges in 1922.

Costs to be paid during the year 1922.	
Interest on total bond indebtedness of $2,112,500	$105,625
Installment one-fortieth of first issue	62,500
Installments one-fifth of second issue	10,000
Operation 8x365x$30.00	87,600
Administration 8x365x$50	146,000
Total	$411,725
Cost of 8 million gallons.	
Cost per million gallons equals	$141.00
Cost per thousand gallons	14½c

Therefore an average charge of 15 cents per one thousand gallons would pay all costs even with interest and installment on the new bond issue. With a gradual decrease in interest, a surplus could again be accumulated as a sinking fund.

In previous assumptions the life of wood stave pipe was assumed as twenty years. The proportion it bears to the whole project in the first installation is about half. At the end of twenty years, then or in 1933, it will be necessary to replace approximately one and a quarter million dollars worth of the system. By that time, half of the original bond issue would have been paid off, and new bonds could be issued for the renewals without increasing the total bonded indebtedness.

In 1935, approximately 10 m.g.p.d. will be used. If interest is paid on $2,500,000 bonds, plus operation and administration costs; and one-fortieth of the original bond issue and one-twentieth of the second bond issue is annually retired, the total costs would be about as follows:

Interest at 5 per cent	$125,000
Installment one-fortieth of $2,500,000	62,500
Installment one-twentieth of $1,250,000	62,500
Operation at $30 per million gallons	109,500
Administration at $50 per million gallons	182,500
	$542,000

$$\text{Cost for 10 million gallons per day} \ldots\ldots \frac{\$542{,}000}{365 \times 10} = \$148.00$$

Or about 15 cents per thousand gallons.

CONCLUSIONS.

Bond Issue.

The preceding general estimates have been based on a number of assumptions, the truth of which are quite problematical. Fundamental was the assumption that the bond issue would be for $2,500,000 in 40-year bonds, one-fortieth of which would be retired each year, and that the interest would be at the rate of 5 per cent. If a higher rate of interest is demanded, water rates must be raised to meet the increased amounts.

On the other hand, it is quite possible that the bond issue would be so arranged that the first bonds would not mature for a period of ten years, thus relieving the district of the burden of retiring a portion of the bonds during the earlier years of its existence when because of smaller consumption the revenues derived from the sale of water would be relatively small. This method of arranging the maturities of the bonds would tend to have the desirable effect of making the water rates more uniform during the entire life of the system, and to thus reduce them at the outset.

This matter involves so many legal problems, and particularly questions of policy which must be decided by the judgment of the Water Commissioners, that no recommendations will be made here.

Effect of Kind of Pipe.

The estimates given are based on the use of wood stave pipe. If riveted steel pipe were used, the rates might be about 10 per cent. higher during the first few years of use, but the average rates would be essentially the same.

Probable Rates.

It is believed that under the least favorable conditions the average rates during the life of the proposed plant need not exceed 15 to 16 cents per thousand gallons, and that even during the first few years they need not exceed 20 cents per thousand gallons.

These rates are materially lower than now paid in Richmond and the East Bay Cities, and more favorable than those enjoyed by many towns and cities of the State which have municipally owned water systems.

CHAPTER XI.

Summary and Conclusions

The present report contains the result of a year's investigation of the requirements of the Richmond Municipal Water District. By direction of the Board of Commissioners the following primary sources of supply have been investigated:

First: Wells within the District.

Second: Surface runoff within and immediately adjacent to the District.

Third: Filtered water from the San Joaquin or Sacramento Rivers.

This report has been preceded by three advance statements dealing particularly with the proposed Sacramento River supply. As a result of these advance statements, the Board on October 9, 1913, decided to adopt this source of supply, and to call a bond election for $2,500,000.

1. The Richmond Municipal Water District includes about 56 square miles of land, excluding land in the Bay in Contra Costa County, California. About 40 square miles of this is level land below elevation 200. The climate is equable, the temperature uniform, the average rainfall about 26 inches. Severe winds are rare.

The urban portion of the district includes about 7,000 acres, most of which in the City of Richmond has been improved within the last ten years. There are many important industrial concerns. Richmond has advantages which insure an exceptionally rapid development as an industrial and manufacturing city.

2. The urban portion of the district grown rapidly from a population of about 1800 in 1900 to about 16,000 in 1913. It is predicted that the population will exceed 42,000 in 1925 and 134,000 in 1955.

The total production of water in the district is estimated at about 3,400,000 gallons per day. Of this, about 1,700,000 gallons per day is used for manufacturing purposes; about 990,000 for domestic purposes, and about 690,000 is diverted outside the district. The average per capita consumption is 71 gallons per day for domestic use, and 123 gallons per day for manufacturing purposes, a total of 194 gallons per day. The industrial consumption is abnormal and will probably decrease with the city's growth. It is estimated that the per capita consumption will increase slowly for the next eight years, and then decrease until in 1955 it reaches a total of 150 gallons per capita per day, 125 of which will be obtained from the proposed works, which will then be required to furnish about 6,000,000 gallons per day in 1920, and about 12,000,000 in 1943.

3. All of the water now being used in the district comes from underground sources. A number of companies are supplying water, the most important of which is the Peoples Water Company, which uses five groups

of wells, producing a total of about 1,700,000 gallons per day, and supplying about 90 per cent. of consumers in Richmond. Their distributing system is composed of pipe too small to furnish adequate fire protection. There is but one small reservoir. Among the smaller water plants are the Union Water Company, Fred Meyers, McEwen Bros., H. F. Brown, West San Pablo Land and Water Company, and Hercules Water Company.

There is no pretense of serving more than about three-eighths of the total subdivided area in the district. Improvements are so scattering that it is difficult to make extensions. Much of the water is too hard and contains too much salt to be satisfactory.

4. A modern public water supply must be pure and wholesome, judged by both health and aesthetic standards. The water must not be objectionably hard, nor contain disease germs. It should be clear and sparkling. For fire protection an ample quantity should be obtainable at proper pressures. Attention to fire protection means a large saving in insurance premiums.

It is desirable that the water rates in Richmond be reduced. They are now materially higher than the average in most California municipalities. Public ownership is highly desirable.

5. The underground water supply of the district originates on adjacent watersheds of limited area. The present wells are being pumped to excess, and are gradually depleting the underground supply so that the water plane is lowering, and the quality has deteriorated by reason of excessive salinity.

A theoretical estimate of the total underground supply which it is practical to develop is about 6,000,000 gallons per day, or about 2,000,000 more than is now being produced.

6. Within and adjacent to the district are the mountainous watersheds of Wild Cat, San Pablo and Pinole Creeks from which it is possible to develop a large surface supply. Estimates of runoff based upon rainfall records at Berkeley and Oakland indicate a possible yield from the San Pablo watershed of about 12,000,000 gallons per day providing there is sufficient storage to conserve all the surface runoff. This could be done by the construction of an earth dam about 134 feet high, forming a reservoir with an area of about 660 acres and a capacity of about 10,000 million gallons. The dam would be costly because foundations are poor. The water obtained could be filtered and conducted to Richmond by a three-mile tunnel.

Similar work could develop about 3,000,000 gallons more per day from the Pinole watershed.

This source of supply is not recommended because it is too limited to meet the ultimate demands of the district because of the legal complications which might result from impounding the surface runoff now supplying wells below, and because of the possibility that the District might be compelled to acquire and depopulate the entire watershed, the bulk of which is now controlled by the Peoples Water Company.

7. A very satisfactory water supply can be obtained for the District by filtering and pumping water from the lower Sacramento or San Joaquin Rivers. The water in the Sacramento River is softer, clearer, of better color, with less sewage pollution, and is less apt to deteriorate than that of the San Joaquin River. It should hence be preferred. The intake should be located as near the mouth of the river and Richmond as possible, without getting salt water. Chlorine determinations at extreme low stages of the river indicate Toland's Landing, opposite Baker's Point, on Sherman Island, as a satisfactory location for the intake. Toland's Landing has physical advantages, chief of which are solid foundations, and the probability of the low water channel being maintained adjacent to the Landing. The quality of the Sacramento River water has been thoroughly investigated, and found to be perfectly satisfactory if properly filtered, and possibly sterilized.

The general features of the proposed conduit comprise a pumping plant at Toland's Landing, 36-inch pipe line to Martinez, mechanical filters and booster pumping plant at Martinez; storage reservoir west of Martinez, and a 36-inch conduit either following the Shore Line or through a three-mile tunnel underneath Franklin Pass to Richmond.

The pumping plants would consist of horizontal, centrifugal, motor-driven pumps, with an ultimate capacity of 22½ million gallons per day. Emergency gasoline engines would be provided. Analysis shows that the most economical size of the pipe, considering first cost and pumping cost, is 35-inch. The pipe line may be built of wood stave pipe, riveted steel pipe, or cast iron pipe. The former is the cheapest, but has the shortest life. The first cost of the latter is prohibitive. The emergency intake at Antioch could be used by transfering machinery from Toland's Landing. The filters at Martinez would be of the mechanical gravity type, with an ultimate capacity of 18,000,000 gallons per day, and would be capable of furnishing water of a thoroughly satisfactory quality.

The conduit would have a capacity of 15,000,000 gallons per day, which is estimated to be necessary to provide for the excess draft during the summer, if an average of 12,000,000 gallons per day were maintained throughout the year.

The tunnel route would be shorter, and involve less pumping, but would eliminate possible water consumers along the Shore Line.

8. A complete design has been made for a distribution system to cover all the subdivided areas in Richmond, and a modification of this design is recommended for immediate installation. The distribution system is designed to furnish water for fire protection purposes at the maximum rate of 27,000,000 gallons per day, or 225 per cent. of the average rate. Balanced storage is provided on opposite sides of the town at about elevation 250, sufficient to furnish water with ample pressure for gravity fire protection. The main reservoir on the east side of town will have an ultimate capacity of 90,000,000 gallons, and a present capacity of half this amount. It will be formed by an earth dam in a ravine at Richmond Junction Heights. On Potrero Heights opposite, will be a balancing reservoir with a capacity of about 2,000,000 gallons. The complete design of the distribution system serves 6250 acres with 1,307,900 feet of pipe from 2 to 30 inches in diameter, about one-third of which is 3 inches and smaller. For immediate installation it is recommended that 2,300

acres be served with 392,270 feet of pipe, about one-fourth of which is 3 inches and smaller. Ample provision is made for hydrants and valves. A high pressure fire protection system is recommended for the Point Richmond Section.

Certain portions of the distribution systems now in use in Richmond may be used if they can be acquired at an attractive figure.

9. General cost estimates have been made for the San Pablo-Pinole Creek supply and for the Sacramento and San Joaquin River supply, both based upon ultimately furnishing an average of 12,000,000 gallons per day and immediately furnishing an average of 6,000,000 gallons per day. Alternate estimates have been made by direction of the Board, for the Sacramento conduit and all portions of the distribution system 18 inches in size or larger, for the use of wood stave pipe, riveted steel pipe, and cast iron pipe.

A summary of the ultimate cost of the San Pablo source complete with distributing system and using wood stave pipe but exclusive of rights of way and lands, is $3,228,009; for riveted steel pipe, practically the same; for cast iron pipe, $3,502,006. To develop this source it might be necessary to acquire the entire 20,000 acres of the San Pablo watershed above the dam site, the cost of which is not included in the above estimates.

The estimated cost of the Sacramento conduit and distributing system for a supply of 12,000,000 gallons per day, using wood stave pipe for conduit and all pipe 18 inches or larger, and including rights of way if the Shore line route is used, is $3,803,862; using riveted steel pipe is $4,246,198; using cast iron pipe is $5,799,217.

The estimated cost of the recommended Sacramento conduit and distribution system with a present capacity of 6,000,000 gallons per day, but with all pipes with a capacity of 12,000,000 gallons per day, including rights of way, following the shore line route, and using wood stave pipe is $2,453,524; using riveted steel pipe is $2,892,518; using cast iron pipe is $4,407,042.

10. If the recommended Sacramento conduit is built it is estimated that during the life of the project water can be sold at an average cost of 15 to 16 cents per thousand gallons. During the first few years, because of smaller consumption, the cost may be as high as 20 to 25 cents per thousand gallons. These rates are materially lower than those now in effect in Richmond.

They are based upon an estimated 40 year bond issue of $2,500,000 at 5 per cent. interest, one-fortieth retired each year. They include all fixed charges, interest, depreciation, operating and distribution expenses.

Appendices

Accompanying this report are ten appendices giving data and reference for further study as follows:

Appendix No. 1.—Engineering organization.

Appendix No. 2.—Present and future valuation of district.

Appendix No. 3.—Other projects for using Sacramento or San Joaquin River water.

Appendix No. 4.—Probable expansion of Peoples Water Company.

Appendix No. 5.—Water projects for San Francisco and other Bay Cities.

Appendix No. 6.—Hetch Hetchy Project.

Appendix No. 7.—Mechanical water Filtration.

Appendix No. 8.—Wood Stave Pipe.

Appendix No. 9.—Riveted Steel Pipe.

Appendix No. 10.—Legal Status of District.

Appendix No. I.

ENGINEERING ORGANIZATION.

This report is submitted by the engineering firm of Haviland, Dozier & Tibbetts, Civil and Consulting Engineers of San Francisco, Oakland and Sacramento, California, the firm being composed of Messrs. P. A. Haviland, Melville Dozier, Jr., Fred H. Tibbetts, O. W. Jasper, Jr., Geo. A. Posey and H. S. Bonte.

The collection and analysis of data, the prosecution of surveys, and the economic study of the various proposed sources of supply, and of proposed construction work, have extended over practically the whole of the year 1913.

A great deal of exceedingly valuable information has been taken from recent reports of various eminent engineers on the water supply of San Francisco and other San Francisco Bay cities. Especial mention should be made of the following:

1. "The Hetch Hetchy water supply for San Francisco, 1912," by John R. Freeman. Of especial use has been Appendix No. 12 of this report, being a report on "Filtered Water Supply for San Francisco," by Allan Hazen, Consulting Engineer, December, 1911.

2. "The Future Water Supply of San Francisco From the Conservation and Use of its Present Resources," by the Spring Valley Water Company, 1912.

3. "The Water Supply of San Francisco," by H. M. Chittenden and A. O. Powell, 1912.

4. Report of Advisory Board of Army Engineers to the Secretary of the Interior on "Investigations Relative to Sources of Water Supply for San Francisco and Bay Counties," February, 1913.

5. Report on "High Pressure Fire Protection System for the City of Berkeley," by J. J. Jessup, City Engineer, May 12, 1913.

6. "Report on the Proposed Filtered Water Supply for the City of Sacramento," by Chas. G. Hyde, 1909.

Free use has been made of standard treatises on Public Water Supplies, especially of the following:

1. "Value of Pure Water"—Whipple.
2. "The Filtration of Public Water Supplies"—Hazen.
3. "Clean Water and How to Get It"—Hazen.
4. "Water Works Management and Maintenance"—Hubbard & Kiersted.
5. "Public Water Supply"—Turneaure & Russell.
6. "Water Supply Engineering"—Folwell.
7. "Water Supply"—Mason.

The chemical and mechanical analyses of water samples and sand have been made by Mr. S. A. Tibbetts, Chemist. The bacterial analyses were made by Dr. Frederick P. Gay, of the University of California.

The detailed compilation of data has been under the immediate direction of Mr. N. D. Baker, Chief Assistant Engineer, in the San Francisco office of Haviland, Dozier & Tibbetts, assisted by Mr. Paul Bailey, Assistant Engineer.

The collection of field data has been chiefly made by Mr. W. S. Farley, formerly City Engineer of Richmond. The field surveys and investigations have been in charge of Mr. G. O. Fraser, Assistant Engineer.

The statistical studies of Chapter 2 and Appendix 2, have been under the direction of Mr. T. D. Kilkenny, Assistant Engineer.

The preparation of maps, plans and diagrams has been under the supervision of Mr. I. H. Smith, Chief Draftsman in the San Francisco office of Haviland, Dozier & Tibbetts. The architectural treatment is due to Mr. J. H. L'Hommedieu, assisted by Mr. G. S. Whitehead. Others who have contributed to the work are the following: Messrs. R. S. Anderson, H. R. Angwin, T. A. Bither, F. H. Carter, C. Coryell, F. C. Dashper, W. S. Edwards, R. S. James, L. E. Joses, W. E. Stoddard, S. R. Van Wyck and R. W. White.

The writers wish to express their appreciation of the hearty cooperation and assistance of the Board of Directors of the Water District, President Levi Boswell, and Directors Chas. P. Blanchard, R. H. Curry, Henry W. Mergenthal, J. B. Willis, H. E. Wyatt, and Secretary J. F. Chandler, and Auditor Wm. P. Wetmore; also Mr. D. J. Hall, Manager and Attorney.

The officials of the various water companies operating in the District have furnished very valuable data.

Appendix No. II.

Present and Future Valuation

METHOD OF FORECASTING ASSESSED VALUATION.

Two general methods may be used in fixing assessed valuation. These methods were explained in detail in the previous discussion of present and future population (Chapter II).

Method No. 1, which involves a comparison with districts similar to the one under consideration, cannot be very satisfactorily used because methods of assessment in various cities vary widely, the classes of property included in the assessment are not known, the variation and the ratio, of assessed to actual valuation is now known, and statistics of assessed valuation for small cities or districts similar to Richmond are not obtainable. Therefore, the study of assessed valuation for the district is confined to use of method of No. 2, which involves projecting ahead the past rates of growth of the district.

The necessary statistics of assessed valuation were obtained from the office of the County Assessor and County Auditor of Contra Costa County. In Table No. 47 the figures are shown segregated under School districts in the same manner as for the population studies of Chapter II, and the totals given for the years 1907-1913 inclusive. Assumptions were made for the School Districts of Sobrante, Sheldon and Orinda Park. Since the assumptions involved relatively small quantities the totals should be close enough for the purpose of this forecast. Footnotes below the table explain the assumptions. Only non-operative property is considered, because taxes levied for district purposes would be confined to this class of property and the percentage of bonded indebtedness for public improvements is usually similarly limited.

Table No. 47—Assessed Valuation of Non-Operative Property in Richmond Municipal Water District.

School District	1907	1908	1909	1910
Richmond	$4,994,166	$6,643,883	$7,421,800	$7,742,495
Stege	906,538	1,339,145	1,801,140	2,240,785
San Pablo	927,987	854,455	889,930	1,110,620
Sobrante	*508,046	*508,046	*508,046	*574,616
Mt. Pleasant	206,285	206,285	206,285	105,630
Sheldon	§144,235	§144,235	§144,235	144,235
Orinda Park	18,524	18,524	18,524	18,524
Total	$7,705,781	$9,714,573	$10,989,960	$11,936,905

Table No. 47 (continued).

School District	1911	1912	1913
Richmond	$8,666,465	$12,358,155	$15,012,640
Stege	2,845,720	1,504,775	1,945,160
San Pablo	1,218,725	1,002,520	1,284,510
Sobrante	*618,471	*741,421	826,171
Mt. Pleasant	96,625	126,725	150,995
Sheldon	177,700	175,875	167,305
Orinda Park	18,524	18,524	‡18,524
Total	$13,642,230	$15,927,995	$19,405,305

*Sobrante School District is not all within the water district.

§Sheldon School District lapsed from 1906 to 1910. The relation was taken as constant previous to 1910.

‡A very small part of Orinda Park District is in the water district. The valuation in 1913 was obtained by multiplying the acreage by the assessed value per acre and taken as constant for the previous years.

Rates of Increase.

Table No. 48 is computed to show the annual percentage increase in assessed valuation for the district from the year 1907 to 1913. Also the valuation per capita upon the basis of the population estimates in Chapter II. The percentage increase in per capita valuation is also set down as a matter of interest. The average rate of increase in the seven year period in assessed valuation is 16.7 per cent. The average per capita valuation $1110, and the average increase in per capita valuation 6.6 per cent per annum.

Table No. 48—Assessed Valuation and Rates of Increase in Non-Operative Property.

Year	Assessed Valuation	First difference	Annual % increase	Valuation per capita	% Increase per capita valuation
1907	7,705,781			870	
		2,018,792	26.2		12.8
1908	9,714,573			982	
		1,275,387	13.0		14.6
1909	10,989,960			1,126	
		946,945	8.6		11.4
1910	11,936,905			1,243	
		1,705,325	14.3		— 6.6
1911	13,642,230			1,160	
		2,285,765	16.8		— 1.2
1912	15,927,995			1,146	
		3,477,310	21.8		+ 8.6
1913	19,405,305			1,245	
			100.7	$7,772	39.6
Average rate			16.7	$1,110	$ 6.4

Table No. 49—Forecast of Probable Future Assessed Valuation of Non-Operative Property.

	MAXIMUM		MEAN		MINIMUM	
Year	Per cent Increase	Valuation	Per capita Valuation	Valuation	Per cent Increase	Valuation
1913		$19,405,305	$1,245	$19,405,305		$19,405,305
	16.0				8.6	
1914		22,500,000	1,205	21,060,000		21,060,000
	15.				8.2	
1915		25,900,000	1,171	22,800,000		22,800,000
	14.				7.8	
1916		29,500,000	1,139	24,600,000		24,600,000
	13.				7.4	
1917		33,350,000	1,110	26,450,000		26,450,000
	12.				7.0	
1918		37,350,000	1,110	29,100,000		28,300,000
	11.				6.6	
1919		41,500,000	1,110	31,750,000		30,200,000
	10.				6.4	
1920		45,700,000	1,110	34,400,000		32,150,000
	9.				6.0	
1921		49,800,000	1,110	36,900,000		34,100,000
	8.				5.6	
1922		53,800,000	1,110	39,500,000		36,050,000
	7.				5.4	
1923		57,600,000	1,110	42,100,000		38,000,000
	6.				5.2	
1924		61,100,000	1,110	44,450,000		39,950,000
	5.				5.0	
1925		64,200,000	1,110	46,750,000		41,950,000
	25.				25.0	
1930		80,300,000	1,110	59,900,000		52,450,000
	25.				20.0	
1935		100,300,000	1,110	74,800,000		63,000,000
	25.				20.0	
1940		125,400,000	1,110	89,900,000		75,700,000
	25.				15.0	
1945		156,800,000	1,110	107,400,000		87,100,000
	25.				15.0	
1950		196,000,000	1,110	127,800,000		100,100,000
	25.				10.0	
1955		245,000,000	1,110	148,700,000		110,110,000

Forecast of Probable Future Assessed Valuation of Non-Operative Property.

In Table No. 49 the figures are tabulated under three headings—the maximum valuation, mean valuation, and minimum valuation. The valuation is forecasted in advance to 1955, advancing by single years to 1925, thence by five intervals. The maximum rate of increase was assumed to be the maximum rate of growth. Thenceforward the rate was decreased one per cent. per year up to 1925, when the rate of 5 per cent. per annum was reached and carried forward to 1955. A total valuation of $245,000,000 was thus reached in 1955. The minimum valuation was started at a percentage increase of 8.6 per cent. which is the minimum rate exhibited in Table No. 48. This rate was decreased in equal decrements to the year 1930. Thenceforward the annual rate was decreased one-half per cent. in each decade and was

compounded at five-year intervals. The valuation reached in the year 1955 is $110,110,000. The probable future mean valuation is assumed not to exceed the predicted minimum up to and including the year 1917, thenceforward it is computed on the assumption of a constant per capita valuation of $1110, for the population forecasted in Table No. 12, giving a mean of $148,700,000, in the year 1955.

Appendix No. III.

Projects for Using Sacramento or San Joaquin River Water for a Municipal Water Supply

PRESENT USE OF RIVERS.

The water from the San Joaquin, and especially the Sacramento River, is now used in its raw or untreated state by many of the small towns and communities along the river banks. Antioch is perhaps the largest town using San Joaquin River water. For a number of years the supply for the town has been pumped directly from the river. The town is close to the mouth of the river where presumably the quality of the water at least as affected by salt water contamination is poorer than at any other point on the river.

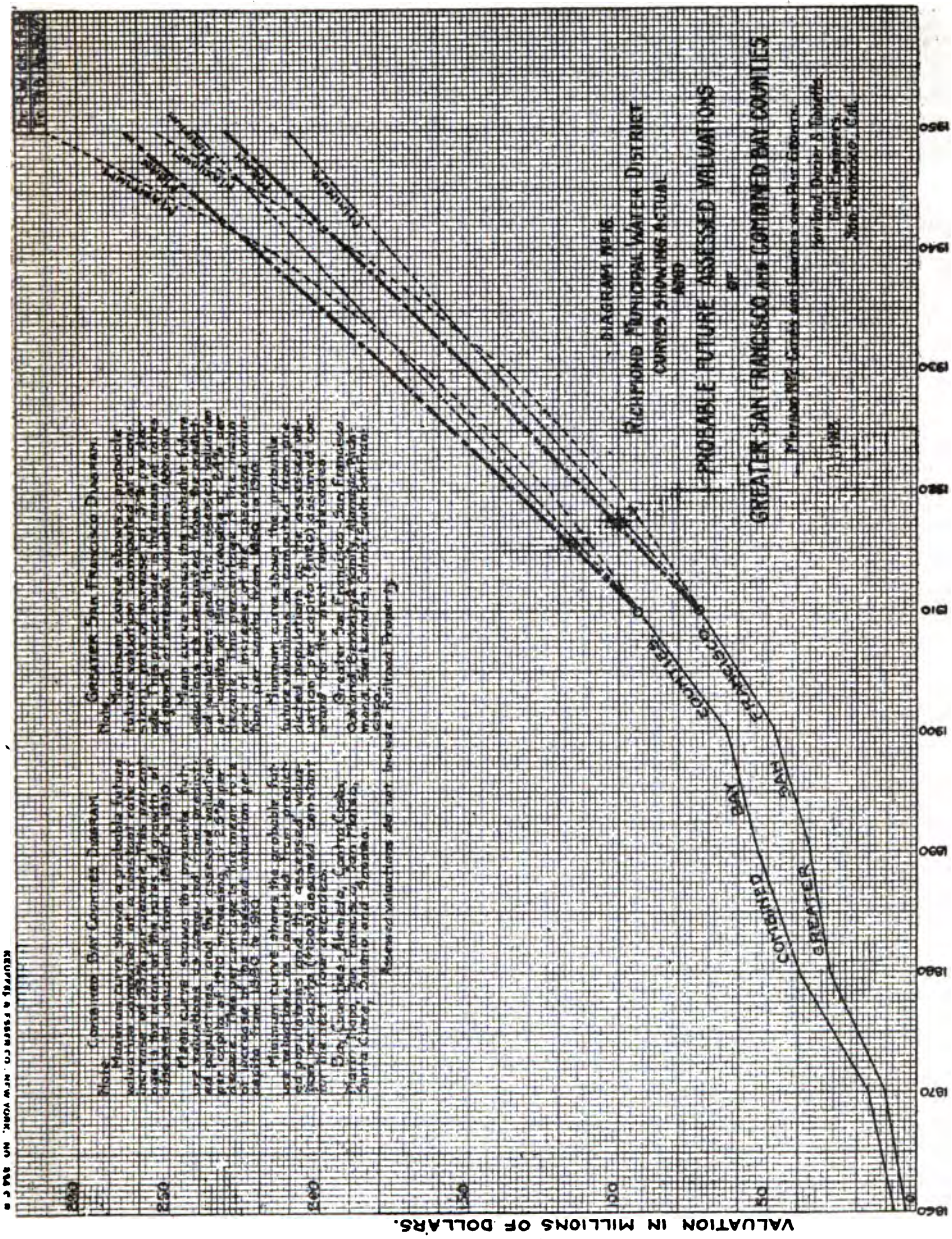
Sacramento, the capital and the fourth city in size of the State of California, has for many years used untreated water from the river. There has been much dissatisfaction, however, especially in recent years, with this source of supply. Many other towns along the Sacramento River, and its tributaries, use the water without treatment.

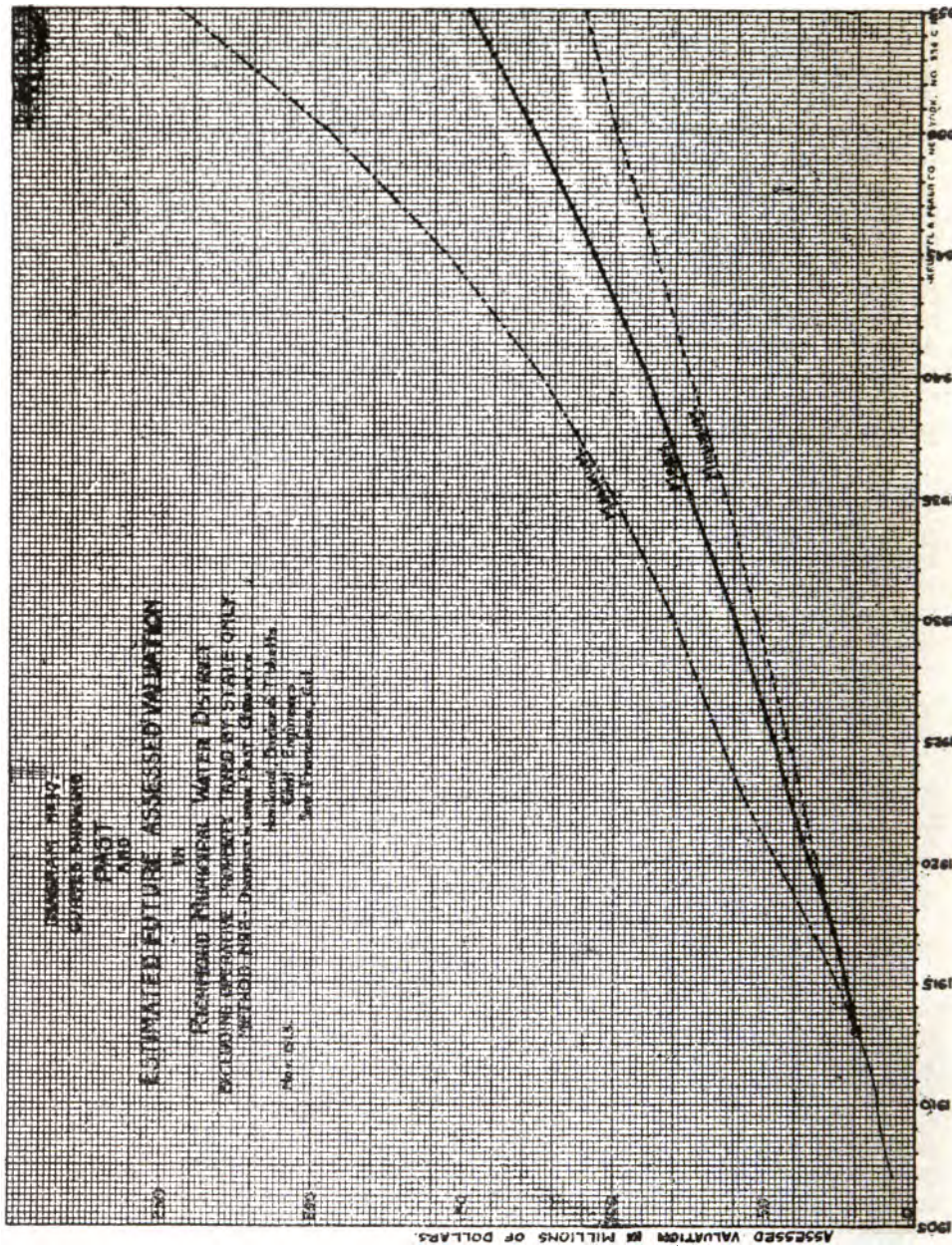
The rapidly increasing population in the valleys of both the San Joaquin and Sacramento Rivers is increasing the danger from sewage pollution. The flow of the Sacramento River is so large, however, that this danger is not apt to become serious for a long time. If the State laws relating to the pollution of water used for public supply were strictly enforced, the danger would be very small.

San Joaquin River—Spring Valley Project.

The use of the San Joaquin River water to supplement the Spring Valley Water Company's Alameda system has been worked out in a general way and described in the report of the Spring Valley Water Company on "The Future Water Supply of San Francisco, From the Conservation and Use of Its Present Resources," submitted to the Secretary of the Interior, October 31, 1912, (See pages Nos. 95 to 118).

This source has been investigated by the Spring Valley's Engineers since 1877. In the report above referred to it is proposed to take water from the San Joaquin River just below the mouth of the Tuolumne and Stanislaus Rivers, pumping from the San Joaquin during freshet stages only in order to get the water of the best quality. The water would be pumped during four to six months of relatively high stages in the spring and summer into the filter and reservoir systems of the Alameda Creek region. It would then be filtered as required through the Company's natural gravel filters in Sunol Valley. Mr. Herman Schussler, Chief Engineer of the Spring Valley Water Company, estimated that from 150,000,000 to 200,000,000 gallons per day could readily be obtained from this source.


GREATER SAN FRANCISCO AND CONTIGUOUS BAY COUNTIES
PROBABLE FUTURE ASSESSED VALUATIONS
OF
RICHMOND WINDSOR WATER DISTRICT
QUINCY SYSTEM ACTUAL
AND
PROBABLE FUTURE
CONTRACTED
GREATER
AREA
ESTIMATED
VALUATION IN MILLIONS OF DOLLARS.
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950


ESTIMATED FUTURE ASSESSED VALUATION
IN
REDWOOD MUNICIPAL WATER DISTRICT
INCLUDING SPECIFIC PROPERTY TRIBUTARY TO STATE ONLY
METHOD USED: Determination of Assessed Valuation
by Land Survey Engineers
Staff Engineers
San Francisco, Cal.
Mar. 1915
ASSESSED VALUATION IN MILLIONS OF DOLLARS.
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955

A report of 200 pages on this supplemental supply was made to the Spring Valley Water Company in 1911, by Prof. Chas. G. Hyde. The above reports were reviewed by the Advisory Board of Army Engineers, who concluded that the low stage flow of the San Joaquin River was so small that excessive storage would be required, unless the point of intake were in the lower reaches of the San Joaquin River, fed by outlet sloughs from the Sacramento. The project was believed to be perfectly feasible with an intake at a point on Old River, known as "Clifton Court." Even with pumping discontinued at low water stages, a supply of perhaps several hundred million gallons daily could be maintained from the reservoirs. Estimates were made of the cost of constructing and operating a 200,000,000 gallon per day supply from this source. The lowest recorded flow of the San Joaquin River was estimated at 230 cubic feet per second. It was shown, however, that the minimum discharge would probably increase in the future owing to irrigation and power development.

Filtered River Water for Sacramento City.

The use of Sacramento River water for the City of Sacramento has been thoroughly treated in an exhaustive report by Prof. Chas. Gilman Hyde to the City of Sacramento, submitted October 15, 1909. In this report it was concluded that the use, by Sacramento, of raw water from the river should be discontinued because of its unsatisfactory quality, particularly from the standpoint of public health. The Sacramento River has so large a low water flow that sewage contamination could never be serious if the water were filtered.

The present daily consumption at Sacramento was estimated at 15,000,000 gallons. By 1950 it might increase to 60,000,000 gallons. The nominal capacity of the plant proposed was 35,000,000 gallons daily, and the estimated cost complete, including land, parking, pumping plants, filter beds, etc., $828,000.00. The estimated annual cost of the 35,000,000 gallon plant operated at the present daily output of 12,000,000 gallons per day would be $108,000.00, or about $25.00 per million gallons.

Proposed Sacramento River Supply for San Francisco.

This subject is thoroughly treated by Mr. Allen Hazen, in Appendix No. 12 of the Freeman Report on the Hetch Hetchy water supply for San Francisco, 1912. The general features and cost estimates are worked out for a project for furnishing by 1917 a supply of 60,000,000 gallons daily with three other installations of the same capacity to follow later as required. The permanent parts of the proposed works were to be immediately constructed to the ultimate required capacity. The estimated cost of the first installation of 60,000,000 gallons per day was given by Mr. Hazen as $24,000,000. This was changed in Mr. Freeman's later supplemental report to about $32,000,000. Over $5,000,000 was for submarine crossings under the Bay. Excluding the Bay Crossing in order to make this project more nearly comparable to the Richmond project, the estimated cost would be equivalent to between $300,000 and $400,000 per million gallons supplied.

The estimated cost of operation, including pumping and filtering was $17.00 per million gallons, of which something over one-fourth was for operating the filters. To deliver the water in San Francisco at an elevation of 280 feet would require about $8.00 per million gallons more for pumping, giving a total of about $25.00 per million gallons.

The position of intake was briefly discussed without accurate data, and the conclusion was reached that the intake should probably be on the Sacramento River near Rio Vista, or on the San Joaquin River opposite Mandeville Island. A discussion previously quoted in this report showed the Sacramento River water to be of superior quality. Both waters could be filtered so as to produce a good potable water at all seasons of the year, removing the turbidity, color and the result of sewage pollution, but the San Joaquin water would contain an excess of mineral matter during part of the year. Sacramento River water would be softer and more attractive physically than the water now supplied around San Francisco Bay.

A number of alternate routes were proposed, the one recommended starting from Rio Vista, crossing the Sacramento and San Joaquin Rivers near Antioch, thence to Walnut Creek, thence through a tunnel to a reservoir in the hills east of Oakland, thence crossing the Bay with submarine pipes opposite Alameda. At the filters, storage was proposed of raw water for two-thirds of an average day's supply. The filters would be similar to those in operation at Watertown, Cincinnati, Columbus, etc. High duty steam pumping plants were proposed with steel and concrete pipe. No difficulty was anticipated in the submarine crossings, for which flexible joint cast iron pipe would be used.

The Army engineers in reviewing this report call attention to the fact that experts believe that in a number of years all cities will filter their supplies from whatever source derived, due to the increased demand for a clear, odorless, perfect water.

The Sacramento water was found to be much softer than the San Joaquin, and less liable to increase in hardness. It was believed that the minimum discharge in the Sacramento River is probably about 5,000 cubic feet per second, and that this is apt to increase in the future rather than to decrease, because of probable irrigation and power developments.

CONCLUSIONS.

From the above, it will be seen that the use of the Sacramento and San Joaquin River waters for municipal supplies has been thoroughly considered by experts and found to be perfectly practical. The only objection to the use of such water for San Francisco was the purely economical consideration of the high cost of pumping.

It is everywhere agreed that the water could be made of satisfactory quality by properly filtering it, and that the supply was ample in amount and otherwise satisfactory. It is also evident that the relative advantage in first cost of the Sacramento River Supply over more distant mountain supplies is greater the smaller the proposed system and the closer the point of diversion and hence should prove more attractive for the Richmond Municipal Water District than for its larger neighbors.

Appendix No. IV.

Probable Expansion of the Peoples Water Company

The Peoples Water Company is a corporation supplying with water the cities on the eastern shore of San Francisco Bay. Their service extends from San Leandro on the south to Richmond on the north, including the cities of Oakland, Berkeley and Richmond.

Their supply is taken from several sources. The San Leandro watershed develops about 6,000,000 gallons per day through storage in Lake Chabot. Series of wells located along the Bay shore at Alvarado, Fitchburg, San Pablo and Richmond, yield about 10,000,000 gallons per day. Tunnels and small surface developments along the foothills yield almost 2,000,000 gallons more per day. The total resources of the company are about 18,000,000 gallons per day.

Part of the distribution system is supplied by gravity from the storage reservoirs. As their system extends over considerable territory, booster pumps are necessary to supply the distributing reservoirs in more remote sections. All the water from the wells is necessarily pumped to the distributing reservoirs. In general, the pressures in the pipes are satisfactory for domestic use. Fire pressures are obtained by the use of fire engines.

Previous to the earthquake in 1906, the service of the Peoples Water Company was quite satisfactory. In 1907 the influx of people to the east bay territory placed a very unexpected draught on their supply, overtaxing its capacity. Previous to this date the normal rate of increase in population in the territory served was about 20,000 per annum. The increase during the year following the San Francisco disaster is estimated at five times this amount. Although the company had a reasonable excess development in their supply, this sudden increase in draught and the stimulated growth thereafter has made it impossible for the company to give first-class service for the last few years.

In 1906 an investigation was started for the extension of their company's sources of supply. A careful and complete report with plans for increasing their supply over 100 per cent. was presented to the company by Arthur L. Adams. Very little of the work recommended for the extension of the supply has yet been constructed. Considerable land has been purchased, however, on the nearby watersheds, which it is proposed to develop. Temporary relief has been sought by sinking additional wells along the Bay shore. At present this source of supply is developed to its limit. Without doubt it has been overdrawn the last few seasons since there has been a marked decrease in the production from some of these wells. Thus drawing on their resources to the utmost extent, the present demand is barely being met.

For meeting future demands, the company seems to be relying on purchasing water from the Spring Valley Water Company. Until the completion of the Calaveras Creek project, the Spring Valley Water

Company may not have more than enough to meet its own requirements. Since this work involves the construction of a large dam which is only just begun, it will probably be two or three years before water can be obtained from this source. The Peoples Water Company will, therefore, have to get along with their own depleted resources as best they can for a few seasons yet. Relief by purchase from the Spring Valley Water Company will hardly be permanent then as in a few years' time the Spring Valley Water Company may need all the water from the Calaveras watershed for its own use.

The Peoples Water Company are apparently making no great effort to relieve their embarrassment. Since it would take several years to develop any of the sources of supply contemplated in their future plans, the water supply situation in the East Bay territory will, therefore, be in a critical condition for the next few years. Under such conditions, the present unsatisfactory service to the City of Richmond by the Peoples Water Company can hardly be expected to improve. The water from the San Pablo and Richmond wells will be needed badly for the Berkeley service. Consequently, it is probable that the Peoples Water Company will welcome the development of a supply for its own use by the Richmond Water District. It is evidently the only recourse the district will have to insure an adequate supply for its inhabitants during the coming years.

Appendix No. V.

Water Supply Projects for San Francisco and other Bay Cities

A number of possible sources for a water supply for San Francisco have been proposed and investigated. Among the most important are:

Enlargement of the Spring Valley Water Company's holdings.
Hetch Hetchy reservoir and adjacent sources.
Stanislaus River.
American and Consumnes Rivers.
Sacramento River.
McCloud River.
Eel River.
Feather River.
Yuba River.
Mokelumne River.
Lake Tahoe.

The **Spring Valley** sources are discussed exhaustively in a report made by the Spring Valley Water Company in October, 1912, to the Secretary of the Interior and the Advisory Board of Engineers. They are also discussed in John R. Freeman's report on the Hetch Hetchy Water Supply for San Francisco.

These sources comprise the Pescadero area, the Peninsula or Crystal Springs area, the Alameda area and the Coyote area, and a few smaller areas of minor importance.

The Alameda area is the largest and most important, containing 620.5 square miles, and is composed of several smaller divisions, as follows:

Calaveras Creek	98.3	square miles
Upper Alameda Creek	35.32	square miles catchment area
San Antonio Creek	38.70	square miles catchment area
Sunol Drainage	49.08	square miles catchment area
Arroyo Valle	140.80	square miles catchment area
Livermore Drainage	258.34	square miles catchment area
Total	620.54	square miles, average rainfall 21.84 inches

Much of the water from these sources is recovered by means of wells and galleries in the gravel beds in the lower portions of the valleys.

The runoff from the Alameda catchment area as measured at the Sunol dam from 1900-01 to 1911-12 was found to be somewhat more than 500,000 million gallons in 12 years or an average of 120 million gallons per day. For a full development of this amount it is proposed to build storage reservoirs and by other means hold the flood water which now wastes over the dam, until it can be used.

The Peninsula system is estimated to be capable of furnishing ultimately about 74 million gallons per day from the different sources as follows:

Crystal Springs	60.7 million gallons per day
San Andreas and Pilarcitos	10.0
Lake Merced	3.5
	74.2 million gallons per day

The Coyote and Alviso and Ravenswood areas are estimated as capable of furnishing a total of 42 million gallons per day.

Chief Engineer F. C. Herrmann of the Spring Valley Water Company estimates the possible ultimate yield from the sources of the company to be as follows:

Peninsula System	74.20 million gallons per day
Alameda System	135.80 million gallons per day
Coyote System	21.00 million gallons per day
Alviso and Ravenswood	21.00 million gallons per day
Total	252.00 million gallons per day

The **Hetch Hetchy Valley** and the Tuolumne River as a source of supply for San Francisco is discussed separately in Appendix No. 6, just following.

Stanislaus River.

The following notes are taken from a report by C. E. Grunsky, and published as Appendix No. 10 of Freeman's report. The watershed area above Knights Ferry is about 935 square miles, but the area under possible storage control is only about 430 square miles or less than half of the total.

It was estimated that with sufficient storage, a supply of 200,000,000 gallons per day could be developed. For an immediate supply of 60,000,000 gallons, the cost is estimated at about $39,000,000, or about $650,000 per million gallons supply.

American-Consumnes Rivers.

In a report by J. H. Dockweiler to the Advisory Board of Army Engineers, it is estimated that a supply of 220 million gallons per day could be diverted to San Francisco from this source at a cost for the first unit of 60,000,000 gallons of about $37,000,000. This is a cost of about $617,000 per million gallons supply.

Sacramento River Filtered Water Supply.

This has already been discussed in Appendix No. 3. The cost of a 60,000,000 gallon supply is estimated at about $400,000 per million gallons.

McCloud River.

The cost of a project to deliver to San Francisco from this source a daily supply of 100,000,000 gallons with 150,000,000 for transbay and valley cities is estimated by the proponents of the project at $42,000,000.

The principal feature of this project would be a conduit about 230 miles long following down the Sacramento River Valley, across Suisun Bay, through the hills of Contra Costa County in tunnel and across the Bay to San Francisco.

Eel River.

This project also involves the construction of a long conduit having a total length of about 148 miles. It has been estimated that from the 268 square miles of watershed above the proposed intake that a supply of about 170,000,000 gallons per day could be brought to San Francisco.

Feather River.

The use of this project would necessitate a conduit about 225 miles long. It has been estimated that a daily supply of 200 million gallons could be brought to San Francisco from this source at a total cost for the first unit of 60,000,000 gallons of about $42,000,000, or about $700,000 per million gallons. This project involves pumping and filtrations.

Yuba River.

The cost of bringing 60,000,000 gallons per day to San Francisco from this source is estimated at about $39,000,000, or about $650,000 per million gallons supply. This project could be ultimately enlarged to 200 or 400 million gallons per day.

Mokelumne River.

It is estimated that a supply of 60,000,000 gallons per day could be developed from this source at a cost of about $31,000,000. It would be possible to develop an ultimate supply of 200 million gallons per day but it is doubtful if this would be permitted. The cost per million gallons of the smaller installation is about $517,000.

Lake Tahoe has been seriously proposed as a source of supply but the report of the Advisory Board of Army Engineers states that the demands are already so great on this source that it is doubtful if San Francisco would be permitted to use it.

Appendix VI.

Hetch Hetchy Project for San Francisco Supply

San Francisco is now supplied with water by the Spring Valley Water Company, which develops surface supplies and underground water from the San Francisco Peninsula and Alameda County. The efforts of the city to obtain a better and municipally owned supply have in recent years been concentrated on the Hetch Hetchy project to bring in mountain water from the Tuolumne River. The present plans call for a branch conduit capable of supplying 50,000,000 gallons daily to the East Bay cities, presumably including Richmond. The Richmond Water District is hence interested in the question of whether it is practical to derive its supply from this source ultimately, and if so, whether it could be brought in in sufficient time to meet the immediate requirements of the district.

The sources of information for this appendix, besides those mentioned in Appendix No. 1, are chiefly the report of the committee on water supply to the City Club of Berkeley, May 15, 1913, and the papers of City Engineer O'Shaughnessy, of San Francisco, and former City Engineers Marsden Manson and C. E. Grunsky, read to the Commonwealth Club on October 8, 1913.

In 1871-2 investigations of a possible water supply for San Francisco were made by General Alexander and Professor Davidson. W. R. Scowden in 1874 investigated the Mokelumne River, Clear Lake, and Calaveras Creek. In 1876-7 Colonel G. H. Mendell made an exhaustive report on a number of possible sources of supply, including Clear Lake, Lake Tahoe, the Feather, American and Mokulemne Rivers.

In 1900 City Engineer C. E. Grunsky made a complete examination, report and surveys covering a period of two years on the Spring Valley Water Company's properties, Bay City Water Company's properties, Lake Tahoe, Clear Lake and the Yuba, Feather, American, Sacramento, Eel, San Joaquin, Stanislaus, Mokelumne and Tuolumne Rivers, and Cache Creek and the Bay Shore gravels. The result was the selection of the Toulumne River with the Hetch Hetchy Valley and Lake Eleanor reservoir sites. Mr. Grunsky's report was complete with plans for conduit, power plants, steel pipe line across the San Joaquin Valley, pumping plants to lift the water over the Coast range, and pipe lines to San Francisco.

The plans have been revised and enlarged by John R. Freeman, Consulting Engineer, and others, in an exhaustive report submitted in 1912. These plans, upon which San Francisco is now endeavoring to proceed, involve the construction of a large masonry dam in the Hetch Hetchy Valley, diverting dams on the Tuolumne River, temporary dams to be later made permanent on Eleanor and Cherry Creeks, and power plants capable of generating 157,500 horsepower. An aqueduct 181.5 miles long is proposed, largely in concrete-lined tunnels. The ultimate capacity will be 400 million gallons per day. The present capacity would be 100 million gallons per day to San Francisco, and 50 million gallons per day to the East Bay Cities. The formation of a metropolitan reser-

voir district is advised, with the purchase of the Spring Valley and Peoples Water Companies' properties, and provision of additional storage near the cities. The total estimated cost is about $40,000,000.

Under the Grunsky plan of 1900, the city acquired water rights, but as a portion of the lands to be used for reservoirs and rights of way belong to the United States as a part of the National Forest Reserve and of the Yosemite National Park, application was made in 1902 to Secretary of the Interior Hitchcock for the right to use these lands. This application was denied on January 20th, 1903, and again on December 22, 1903. A congressional bill granting these rights was drafted in December, 1903, but was not considered. In 1905 the subject was presented to the President, who referred it to Secretary of Commerce and Labor Metcalf, who denied the application. After a hearing in San Francisco in July, 1907, Secretary Garfield granted to San Francisco and other cities, in May, 1908, the desired permits. The surveys were commenced, and a bill prepared to perpetuate the permit. This failed to come to a vote. When Taft became President, Secretary Ballinger gave an order to San Francisco to show cause why the Garfield permit should not be revoked. The subject was dormant for four years, when Secretary Fisher reopened the inquiry after Mr. Ballinger went out of office. The city then employed Mr. Freeman to prepare the report above mentioned. His report was submitted to the Advisory Board of Army Engineers, who were favorable. Nevertheless, Secretary Fisher recalled the permit, and the matter was submitted to Secretary Lane March 13, 1913, who again denied the application.

The opposition to this project has come from a number of sources, the most potent of which are the Spring Valley Water Company, and recently various power companies operating in the Sierras. The irrigation districts supplied by the Tuolumne River have forced many favorable concessions from San Francisco. "Nature Lovers" desirous of maintaining the Hetch Hetchy Valley in its natural state have steadily opposed the project. Other opposition has come from various parties with other sources of supply to offer.

The Raker bill has passed the House of Representatives of the present Congress, and is now, December 1, 1913, about to be considered by the Senate, with a good chance of passage, which may end the twelve years' fight over the comparatively simple requirements of the city from the national government. The bill will be stubbornly opposed, however, and if passed by the Senate, the fight will be transferred to the President, and further obstacles will undoubtedly be presented. Among the things which the Raker bill requires from San Francisco, are the following:

1. Scenic road construction at a cost of $500,000, to $1,000,000, together with maintenance of these roads, with an annual cost of $25,000 to $50,000.

2. Annual payments to the government of $15,000 to $30,000 per year.

3. Initial expenditure primarily for irrigationists of $500,000 to $1,000,000 for storage.

4. Transfer to the government of lands which have been costly to the city.

5. Possible forfeiture of the city's rights, privileges, and even construction work in case the water and power is not developed in the prescribed manner.

To the Richomnd Municipal Water District now in immediate and urgent need of a new supply, the most significant feature of the history of the Hetch Hetchy project is the certainty of long additional delays before water could actually be delivered from this source to the East Bay cities. Mr. C. E. Grunsky, former City Engineer of San Francisco, and the original proponent of the Hetch Hetchy project, stated on October 8, 1913, "Generally three to five years are consumed in actual construction, and to have twice this time elapse from the inception of the project until definite conclusions are reached as to the source of supply, and the character of the work, is not unusual." He also calls attention to the fact that the new plans and the restrictions of the Raker bill so change the project from that for which the people voted bonds in 1909, that if the Raker bill becomes a law it seems likely that there will have to be a resubmission of the water question to the electors. Former City Engineer Manson stated at the same meeting in referring to the "hold up" of the Raker bill, that "It is to be regretted that the gentleman did not forecast the litigation which this bill will surely inaugurate."

In conclusion the writers have no criticism of the Hetch Hetchy project, and even consider it possible that it may be the ultimate source of supply for the Richmond Municipal Water District. The Freeman report upon which San Francisco is proceeding, states, (see page 184 of this report) in no uncertain terms that filtered water from the Sacramento River can be made of thoroughly satisfactory quality. The Richmond Municipal Water District can get such water delivered to consumers in one-tenth of the time that San Francisco has used in efforts to obtain the right to begin work. In the words of Mr. Grunsky, the foremost advocate of the Hetch Hetchy project, "In the case of the Hetch Hetchy project twelve years have already passed and we are not yet at the point where we had hoped we would be ten years ago."

Appendix VII.

Mechanical Water Filtration Bibliography and Examples

The following is a partial list of references to recent engineering literature bearing on the subject of mechanical filtration:

"Water Supply Engineering," Folwell.
"Water Filtration Works," Fuertes.
"Clean Water and How to Get It," Hazen.
"The Filtration of Public Water Supplies," Hazen.
"Water Supply," Mason.
"American Civil Engineers' Handbook," Merriman.
"Public Water Supplies," Turneaure & Russell.
"Transactions—American Society of Civil Engineers"—

Vol. 43 (1900) Test of Mechanical Filters.
44 (1900) Filtration of Water for Public Use.
50 (1903) Filters at Jersey City, N. J.
54-D (1905) Purification of Water for Domestic Use.
59 (1907) Discussion on Water Supplies.
67 (1910) Filters at Columbus, Ohio.
72 (1911) Filters at Washington, D. C.

United States Geological Survey—Water Supply Paper No. 315, "The Purification of Public Water Supplies."
"The Engineering Record"—

Apr. 23, 1910—Filters at New Orleans.
Nov. 26, 1910— " " Toledo, Ohio.
Jan. 21, 1911— " " Bangor, Me.
Apr. 1, 1911— " " Fort Collins, Colo.
June 3, 1911— " " Rock Island, Ill.
June 3, 1911— " " Cohoes, N. Y.
June 17, 1911— " " Charleroi, Pa.
Nov. 18, 1911— " " Minneapolis.
Jan. 27, 1912— " " Kansas City, Mo.
Mar. 9, 1912— " " Montreal.
May 11, 1912— " " Evansville, Ind.
June 29, 1912— " " New Croton Supply.
Aug. 17, 1912— " " Albany, Ore.
Aug. 24, 1912— " " Fort Worth, Texas.
Sept. 14, 1912— " " Cumberland, Md.
Oct. 19, 1912—Regulating Devices.
Sept. 13, 1913—Jewell Filtration Co. Patent Suit.
Nov. 15, 1913—Filters at Albany—Problems of Putting Plant into Operation.

"The Engineering News"—

June 18, 1908—Filters at New Orleans.
Feb. 4, 1909— " " Edinburgh.
May 4, 1911— " " Baltimore, Md.
Oct. 5, 1911— " " Toledo, Ohio.
June 27, 1912— " " Minneapolis.
Oct. 17, 1912—Sanitation of Water Supplies.
Dec. 26, 1912—Filters at Ottawa.
Oct. 2, 1913— " " Panama.
Oct. 23, 1913— " " St. Louis.

The following is a list of references to recent engineering literature giving operation results of filters in use:

"Engineering Record":—
June 25, 1910—Cincinnati.
Sept. 24, 1910—Chicago.
Jan. 28, 1911—Harrisburg, Pa.
Mar. 18, 1911—Cincinnati.
Sept. 23, 1911—New Orleans.
Oct. 7, 1911—Minot, S. D.
Dec. 9, 1911—Rock Island, Ill.
Jan. 13, 1912—Columbus, O.
Feb. 24, 1912—Harrisburg, Pa.
May 18, 1912—Louisville, Ky.
Aug. 31, 1912—Columbus, O.
Sept. 7, 1912—Bangor, Me.
Dec. 7, 1912—Cincinnati.
July 5, 1913—Clarksburg.

The following list gives some of the larger cities in this country using water supplied by mechanical filtration plants with the approximate capacity of each in million gallons per day:

Cincinnati	112	Columbus	30
New Orleans	40	Hakensack	24
Minneapolis	39	New Milford	24
Toledo	39	Atlanta	20
Louisville	36	Harrisburg	20
Little Falls, N. J.	32	Grand Rapids	16
Montreal	30		

Appendix No. VIII.

Wood Stave Pipe Bibliography and Examples

The following is a partial list of references to recent engineering literature bearing on the subject of the use, design and probable life of wood stave pipe:

"Water Supply Engineering," Folwell.
"American Civil Engineers' Handbook," Merriman.
"Treatise on Hydraulics," Merriman.
"Reservoirs for Irrigation Water, Power and Water Supply," Schuyler.
"Public Water Supplies," Turneaure & Russell.
"Irrigation Engineering," Wilson.
"Hydraulic Tables," Williams & Hazen.
"Transactions—American Society of Civil Engineers"—
Vol. 36 (1896) The Astoria Water Works.
38 (1897) Pipe Line of the Pioneer Electric Power Co.
40 (1898), 44 (1900) Flow of Water in the Pipe Line of the Pioneer Electric Power Co.
41 (1899) Stave Pipe—Its Economic Design and the Economy of Its Use. (This article gives a very complete treatise on design of wood-stave pipe.)
58 (1907) Additional Information on the Durability of Wood-Stave Pipe.
70 (1910) Water Supply of the El Paso and Southwestern Ry.
74 (1911) Experiments on the Flow of Water in Wood-Stave Pipe.

"The Engineering News"—
Oct. 11, 1906—The Astoria Pipe Line.
Sept. 3, 1908—Diagram for Band Spacing.
Sept. 24, 1908—Diagram for Band Spacing.
Apr. 1, 1909—Water Supply for Vancouver, B. C.
June 15, 1911—Leakage Experiments.
Oct. 5, 1911—Design of Shoes for Bands.
Mar. 16, 1912—Pipe Line at Atlantic City, N. J. (This article shows the advantage of wood pipe through salt marshes.)
Mar. 28, 1912—Wood Pipe of the Yakima Project, U. S. Reclamation Service.
Sept. 4, 1913—Pipe Line of the Madison River Power Co. (This pipe is the largest ever built.)

"The Engineering Record"—
Nov. 24, 1900—Stave Pipe for Force Mains.
Sept. 1, 1906—Water Supply for Lynchburg, Va.
Mar. 23, 1907—Stave Pipe in Southern California and Montana.
June 15, 1907—Wood Pipe in the Chile Mines.
June 15, 1907—The Denver Water Works.
Sept. 7, 1907—Pipe Line of the Great Northern Power Co., Minn.
Nov. 16, 1907—Pipe Line of the Black Hills Traction Co., S. D.
May 2, 1908—Hydraulic Grading on the Chicago, Milwaukee & St. Paul R. R. (This pipe holds the record for maximum pressure.)
Feb. 26, 1910—Pipe Line of the Madison River Power Co., Mont.
Apr. 2, 1910—Pipe Line of the Utah Light & Ry. Co.
Dec. 24, 1910—Water Supply for Vancouver, B. C.
June 17, 1911—Pipe Line of the El Paso & Southwestern R. R.

"The Engineering Record"—

Nov. 18, 1911—Distribution System of the Pueblo-Rocky Ford Irrigation Project.

Nov. 25, 1911—Water Power Development of Mohawk Hydro-electric Company, N. Y.

Mar. 30, 1912—Water System of Denver, Colo.

The following is a partial list of important existing wood stave pipe lines:

Location.	Constructed.	Diameter, Inches.	Length, Miles.	Maximum Head, Feet.
(a) Manchester, N. H.	1874	72	0.1	38
Denver, Colo.	1889	30	20.0	185
Provo, Utah	1891	14	3.7	...
Butte, Mont.	1892	24	9.0	202
Astoria, Ore.	1895	18	7.5	175
St. Paul, Minn.	1896	42	1.5	...
Los Angeles, Cal.	1896	30	7.5	105
Ogden, Utah	1897	72	5.1	117
Los Angeles, Cal.	1898	14	7.5	...
Lynchburg, Pa.	1906	30	18.5	...
Madison River Power Co., Mont.	1906-8	120-144	3.0	25
Tumwater, Wash.	1909	102	2.1	170
Vancouver, B. C.	1910	30	4.3	210
Atlantic City, N. J.	1911	48	7.0	173
Pueblo, Colo.	1911	84	3.5	...
Mohawk Hydro-electric Co., N. J.	1911	78-96	2.0	160
Pac. Gas. & Elec. Co., Cal.	1913	96	...	...
(b) Madison River Power Co., Mont. Power Co., Mont.	1913	156	...	...
(c) Chicago, Milwaukee & St. Paul R. R. Wash.	....	38	0.2	400

(a) First pipe constructed. (b) Largest pipe. (c) Greatest pressure.

Appendix No. IX.

Riveted Steel Pipe
Bibliography and Examples

The following is a partial list of references to recent engineering literature which deals with the subject of riveted steel pipe:

"Water Supply Engineering," Folwell.
"American Civil Engineers' Handbook," Merriman.
"Treatise on Hydraulics," Merriman.
"Public Water Supplies," Turneaure & Russell.
"Irrigation Engineering," Wilson.
"Hydraulic Tables," Williams & Hazen.
"Transactions—American Society of Civil Engineers"—

Vol. 35 (1896) Flow of Water in 48-Inch Pipes.
36 (1896) The Astoria Water Works.
38 (1897) The Distortion of Riveted Steel Pipe by Back Fill.
38 (1897) Pipe Line of the Pioneer Electric Power Co.
40 (1898) Flow in the Pipe Line of the Pioneer Electric Power Co., First Series.
44 (1900) Flow in the Pipe Line of the Pioneer Electric Power Co., Second Series.
42 (1899) Friction Coefficient for Riveted Steel Pipe.
51 (1903) A Study of Flow in Water Pipe.

"The Engineering News"—

Apr. 26, 1906—Life of Steel Pipe.
May 17, 1906—Pipe Line through the salt marsh at Atlantic City, N. J.
May 28, 1908—The failure of the Rochester Line. (An extensive article on corrosion.)
Jan. 6, 1910—Ingot Iron for water pipes.
Sept. 29, 1910—The Rochester Line.
Oct. 27, 1910—"Steel Pipe for Water Works." (A complete article on the history, preservation, etc.)
Nov. 17, 1910—The electrolysis suit of Peoria.
Dec. 8, 1910—The electrolysis suit of Peoria.
Jan. 26, 1911—Strength of various types of joints.
Feb. 16, 1911—Steel pipe through salt marshes.
Mar. 23, 1911—Corrosion of Steel.
May 25, 1911—The Portland Water System.
June 15, 1911—Steel vs. Cast Iron for Water Pipes.
July 27, 1911—Collapse of the Portland Pipe.
Aug. 24, 1911—The electrolysis suit of Pittsburg.
Aug. 24, 1911—The Coolgardie Pipe Line—Investigation of the failure of long pipe line in Australia.
Nov. 16, 1911—Corrosion of Steel.
Dec. 21, 1911—Corrosion of Steel.
Feb. 15, 1912—The coating of the National Tube Co.
Aug. 22, 1912—Leaks in the Schenectady Line.
Nov. 7, 1912—Mill Scale as a Cause for Pitting.

"The Engineering Record"—

Jan. 25, 1908—Tuberculation of Steel Pipes.
Mar. 19, 1910—The Action of the St. Louis Water on Pipes.
Apr. 23, 1910—Corrosion of Metals by Water.
Oct. 1, 1910—Steel Pipes for Water Works.
Oct. 8, 1910—Pipe Line of Newark, N. J., across the Potomac Swamp.
July 8, 1911—Pipe Line of Uncompahgre Valley Project, U. S. Reclamation Service.
Oct. 28, 1911—The Corrosive Effects of Different Waters.
Feb. 17, 1912—Coating of the National Tube Company.
Mar. 9, 1912—The Nichol Coating.

The following is a list of important riveted steel pipe lines constructed before 1906. Since that time the list has grown enormously so that any complete compilation is impossible. The earlier examples are most useful in judging of the efficiency and probable life of this form of pipes:

Location	Constructed	Size inches	Length miles
Pittsburg, Pa.	1871	50	0.6
East Jersey Water Company	1891	36–48	27.0
Rochester, N. Y.	1893	39	27.0
Portland, Ore.	1894	33–42	24.0
Allegheny	1895	60	9.0
East Jersey Water Co.	1895-6	42–48	24.0
New Bedford, Mass.	1896	42–48	9.0
Ogden, Utah	1896	72	1.0
Minneapolis	1897	50	7.0
Seattle, Wash.	1899	42	6.0
East Jersey Water Company	1899	51	9.0
Utica Power Company, N. J.	1900	84	0.2
Pittsburg, Pa.	1901	42–51	5.0
Jersey City, N. J.	1902	72	18.0
Newark, N. J.	1903	60	7.0
Pittsburg, Pa.	1908	24–96	8.0

Appendix No. X.

Legal Status of the Richmond Municipal Water District

The Richmond Municipal Water District was formed in accordance with the provisions of an act entitled "An act to provide for the incorporation and organization and management of municipal water districts," approved May 1, 1911, statutes page 1290, amended December 24, 1911; statutes of extra sessions, 1911, page 92.

The act provides that water districts may be formed within any one county and comprise an entire city and if desired, such portions of the surrounding territory within the county as it may be deemed advisable to include within the district.

Broadly speaking, the district is empowered by law to acquire a proper source of supply of water for the district, to issue bonds and sell them, and to otherwise raise funds for the construction of works for the development and distribution of water within the district; for the acquirement of any necessary lands or rights of way; for the purchase of water for use in the district, and for the sale of water and fixing of rates for the same; for the acquirement of any systems now existing for the purpose of supplying water, and generally to deal with all matters relating to and necessary for the development and operation of a publicly owned system for supplying water within the district. It is also empowered to sell water outside of the district. The district may be increased in size by the annexation of territory lying without the district by means of elections held both within the district and in the territory which it is proposed to annex, generally speaking, in the manner by which municipalities are enabled to annex and take in outside territory. There is one additional director for each municipality which is incorporated within the limits of the district.

For a year or more immediately preceding the formation of the Richmond Municipal Water District relief from the existing conditions relative to the water supply of portions of the city, and a general feeling of dissatisfaction with the service of the water companies in Richmond, was the topic of much consideration and discussion by a number of improvement clubs, the city council, and other public bodies of the city. As a result of this discussion, and in response to a general desire for improvement, definite steps were taken for the formation of the district, and the vote in favor of its creation indicates how general was the desire for this improvement.

An election was called by the Board of Supervisors of Contra Costa County in response to a petition asking that the same be held. At this election, which was held on December 3, 1912, the vote in favor of creating the district was 797 against 51 votes opposing the creation of the district.

At this election, Chas. E. Blanchard, R. H. Curry, A. J. Timmons, J. B. Willis and H. E. Wyatt were elected directors, and H. W. Mer-

genthal was appointed by the Board of Supervisors, and Levi Boswell was appointed by the City Council, to serve as directors. This Board organized and elected Levi Boswell as President, and appointed D. J. Hall as Manager, J. S. Chandler as Secretary, W. P. Wetmore as Auditor, and Haviland, Dozier & Tibbetts, as Engineers.

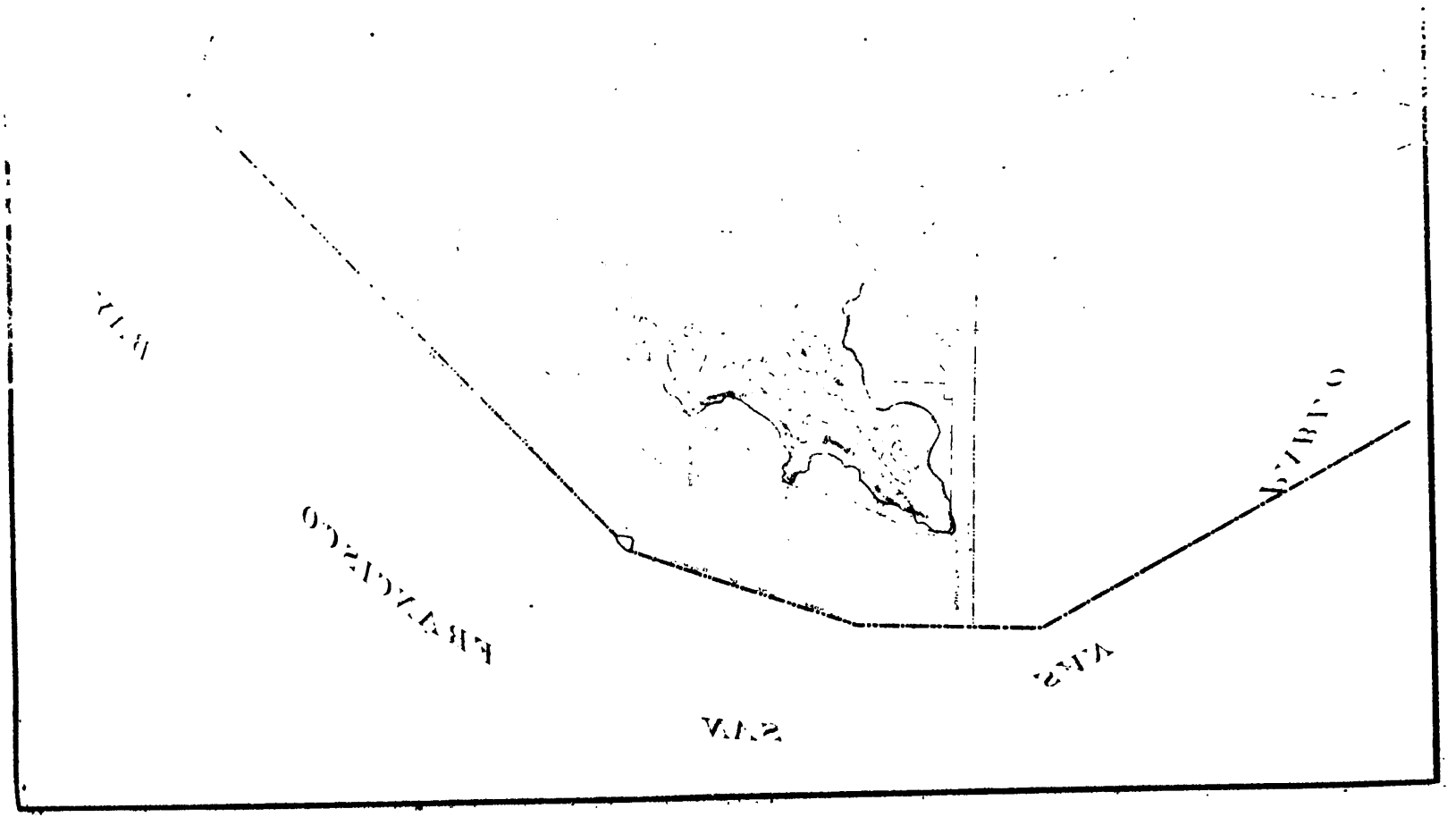
According to the official description, the District includes the following:

Beginning at the common corner of Marin and Contra Costa counties and San Francisco City and County, as established by Section 3950 of the Political Code of the State of California, said point being on westerly boundary line of the City of Richmond, Contra Costa County, State of California, and running thence along said westerly boundary line of the City of Richmond, said line being the westerly boundary line of Contra Costa County, northerly to the northerly boundary line of the City of Richmond; thence leaving the boundary line of the City of Richmond and running along the westerly and northwesterly boundary line of Contra Costa County northerly and northeasterly to an intersection of the said northwesterly boundary line of Contra Costa County and a direct extension northerly of Course No. 623 of the exterior boundaries of the Rancho San Pablo as said Course No. 623 is given in a tabulation of the exterior boundaries of the said Rancho San Pablo on that certain map entitled "Map of the San Pablo Rancho," accompanying and forming a part of the Final Report of the Referees in Partition, dated September 1, 1892, and filed in the office of the County Recorder of Contra Costa County, California, March 1, 1894; thence along the last said extension and along the northeasterly boundary line of the San Pablo Rancho southeasterly and northeasterly and southeasterly to an intersection of the northeasterly boundary line of said San Pablo Rancho, and the northwesterly boundary line of the Rancho El Sobrante as last said boundary line is delineated on that certain map entitled "Map of the Rancho El Sobrante, accompanying and forming a part of the Final Report of the Referees in Partition of said Rancho, dated July 10, 1909," and filed in the office of the County Recorder of Contra Costa County, California, March 14, 1910; and running thence along the northerly and easterly boundary line of the said Rancho El Sobrante easterly and southerly to a point on the said easterly boundary line of the said Rancho El Sobrante distant thereon south 0 degrees 10 minutes west 37.33 chains from the southeasterly corner of Lot No. 2, as said Lot No. 2 is delineated and so designated on the aforesaid map of the Rancho El Sobrante, said point being designated on the said Map of the Rancho El Sobrante as follows: Post E. S. M. V. (granite post) SW. corner Rancho Boca de la Canada de Pinole; thence from the last described point in a direct line southwesterly to the southwesterly corner of Lot 56, as said Lot 56 is delineated and so designated on the aforesaid "Map of the Rancho El Sobrante," said corner of said Lot 56 being on the boundary line separating Contra Costa County from Alameda County; thence along the said boundary line separating Contra Costa County from Alameda County northwesterly and westerly to the southerly boundary line of the City of Richmond; thence along the southerly boundary line of the City of Richmond, westerly to the southwesterly boundary line of the City of Richmond, last said line being the dividing line dividing Contra Costa County from San Francisco City and County; thence along the said line dividing Contra Costa County from San Francisco City and County northwesterly to the point of beginning.

The territory included within the foregoing boundaries comprises and includes all of the City of Richmond and certain unincorporated territory contiguous thereto, and all situated in the County of Contra Costa, State of California.

Since the formation of the Board on April 7, 1913, it has held regular meetings three and four times a month. The members of the Board individually and collectively have devoted themselves energetically to the complex problems that confronted them. With the assistance of their engineers they have carefully inspected and thoroughly studied all possible sources of supply both within and without the district. The water plants of the neighboring cities as far down as Palo Alto and San

Jose have been visited; together with the entire Contra Costa County waterfront as far as 10 miles above Antioch. The location of the intake, pumping plants, filters, reservoirs, tunnels and all other portions of the proposed Sacramento River conduit have been carefully examined as well as the proposed dam sites and water producing areas of the San Pablo, Pinole and Wild Cat Creek watersheds. The directors have thoroughly familiarized themselves with the District's needs and the possibilities of providing an efficient water supply.



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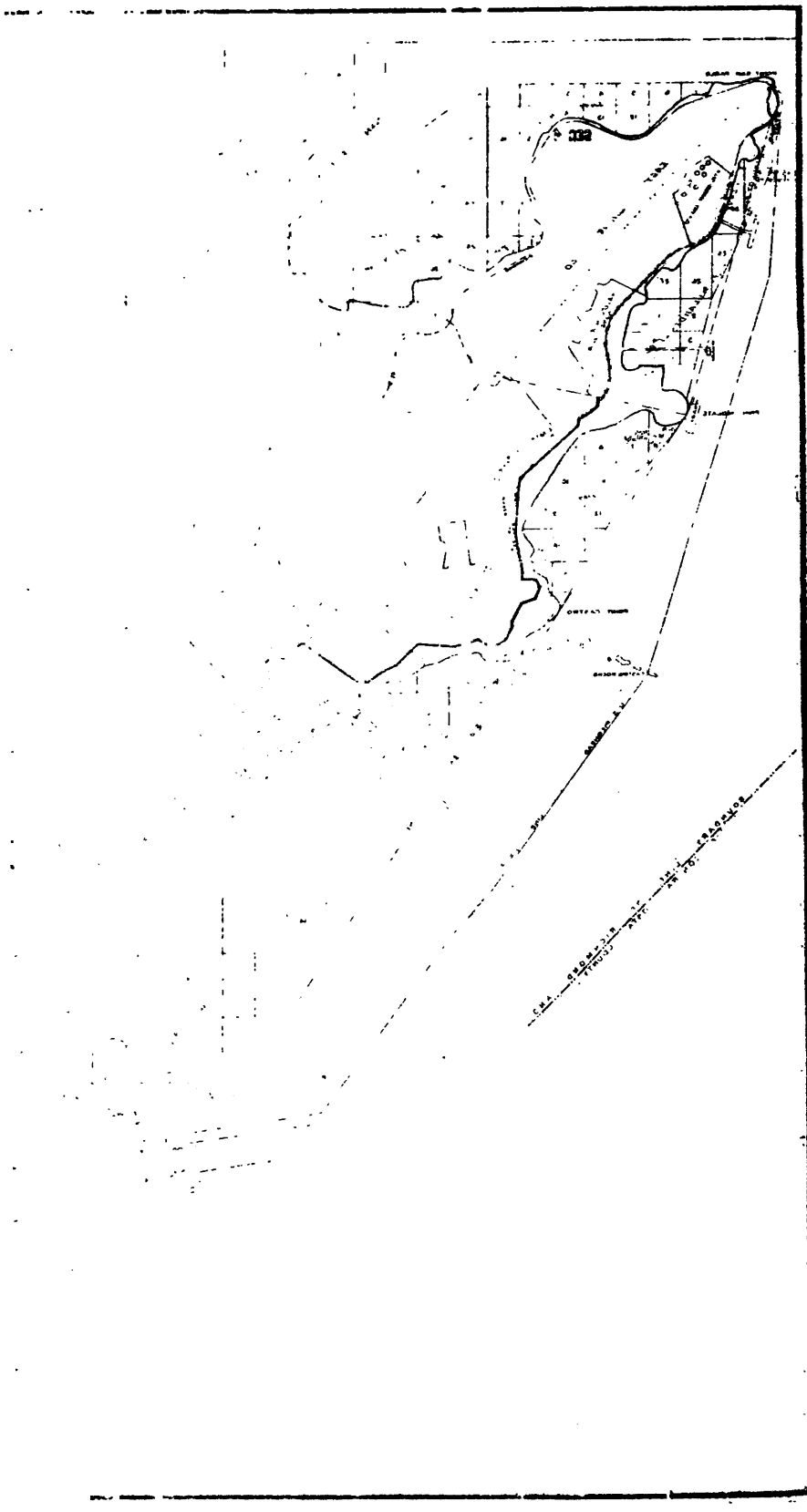

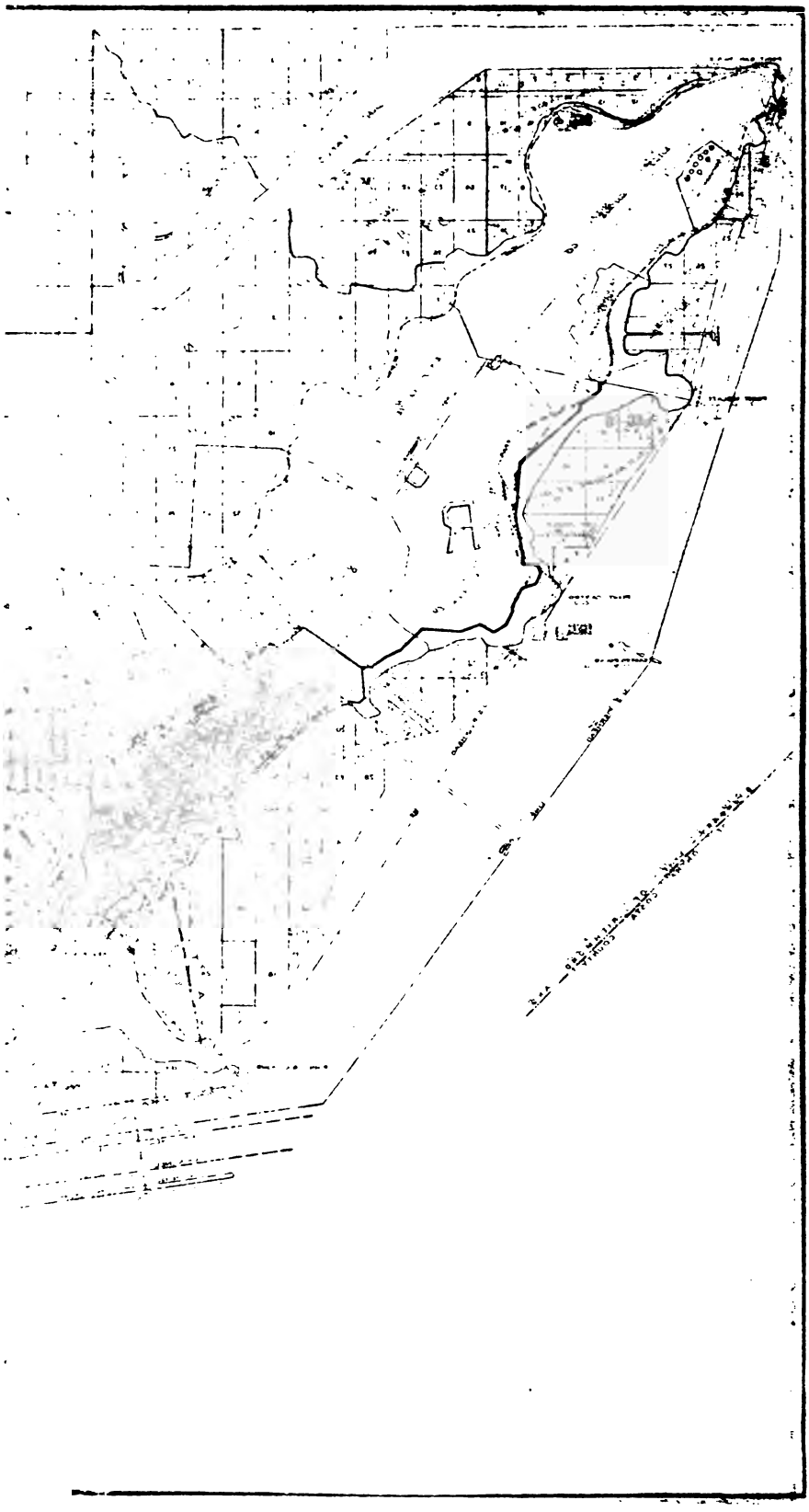

PROPOSED
INNER HARBOR

SAN FRANCISCO BAY
POINT RICHMOND

RICH

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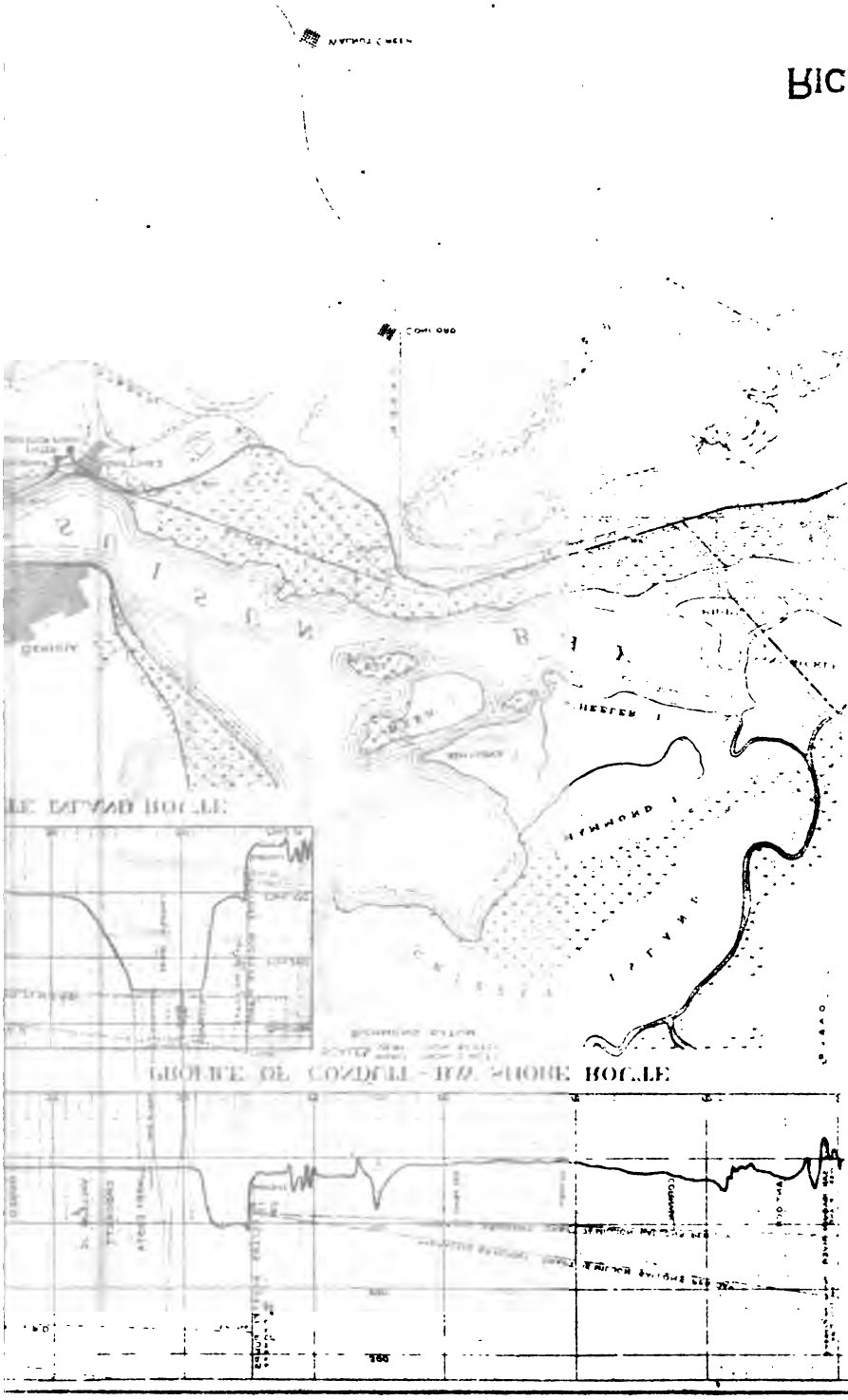

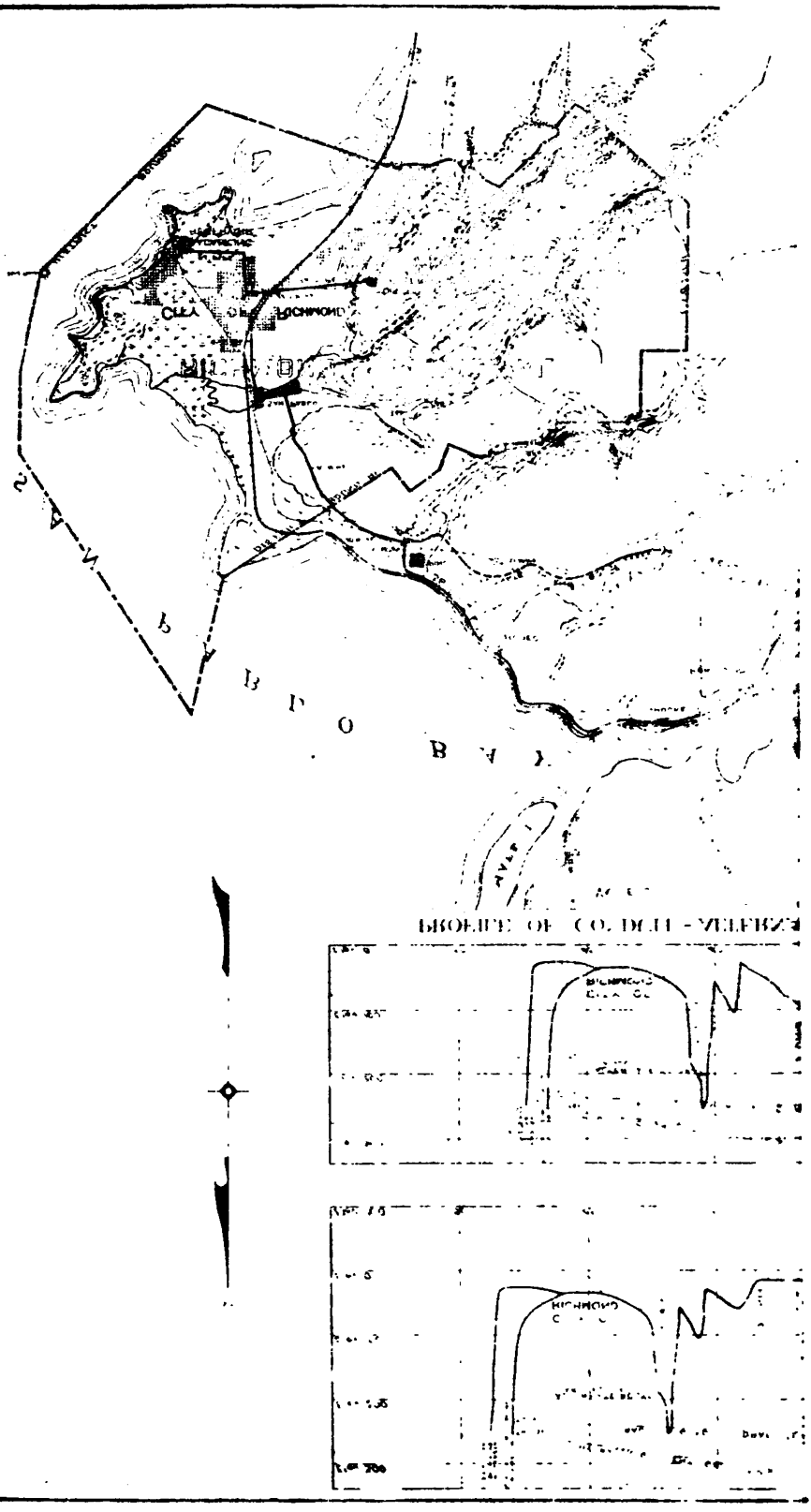
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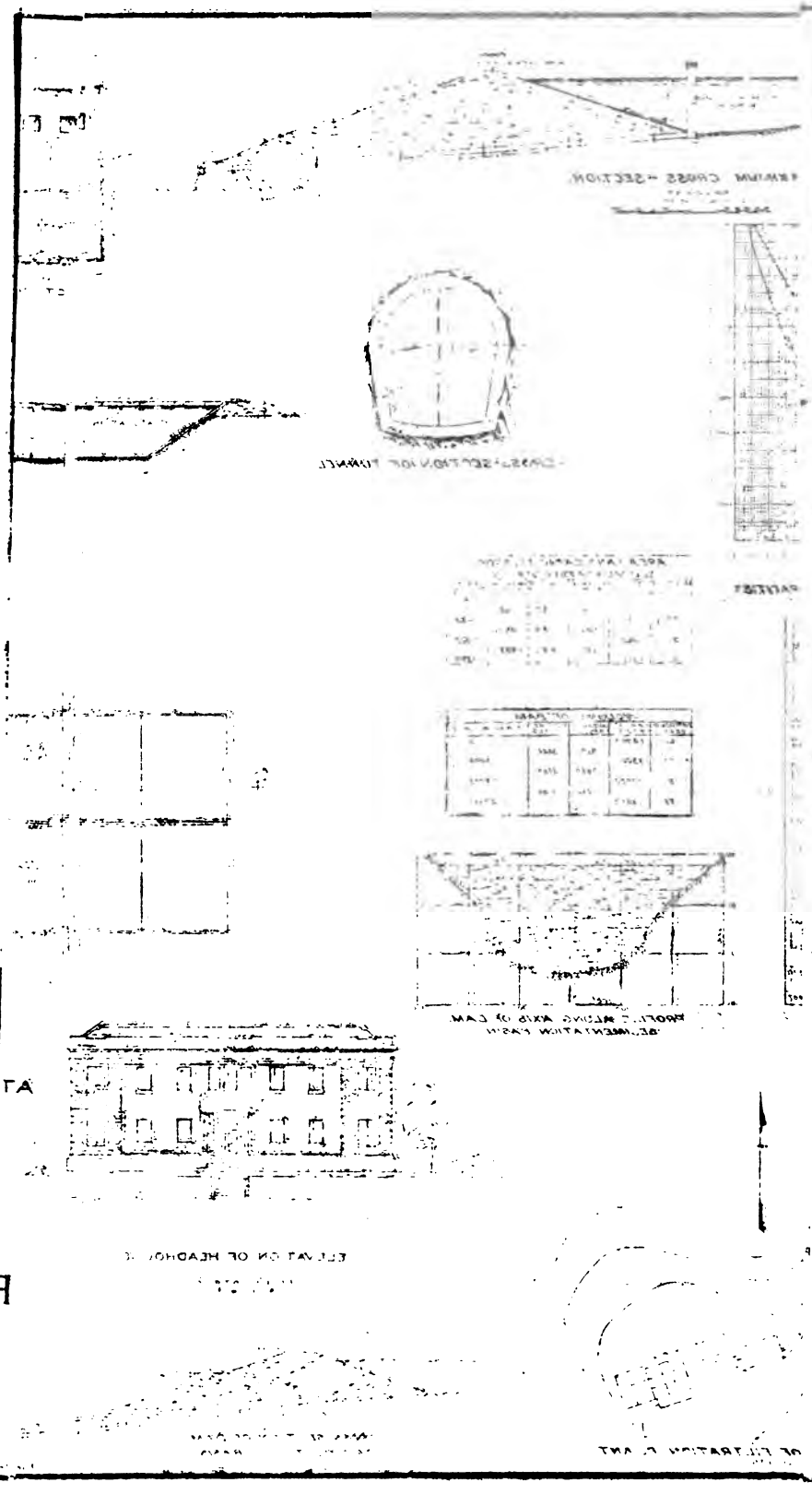
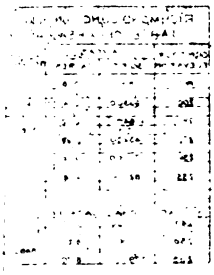
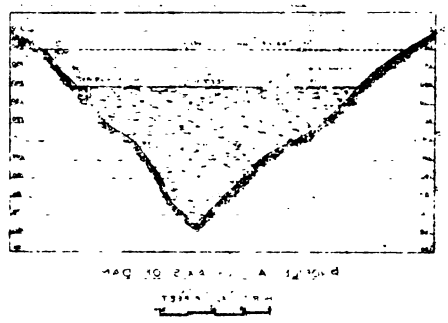
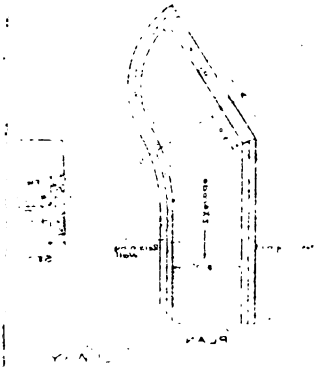
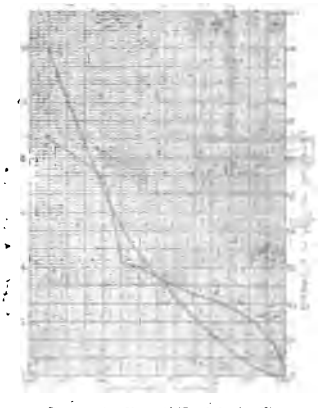


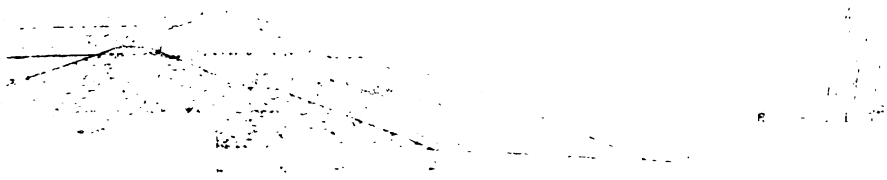
MARTINEZ RESERVOIR

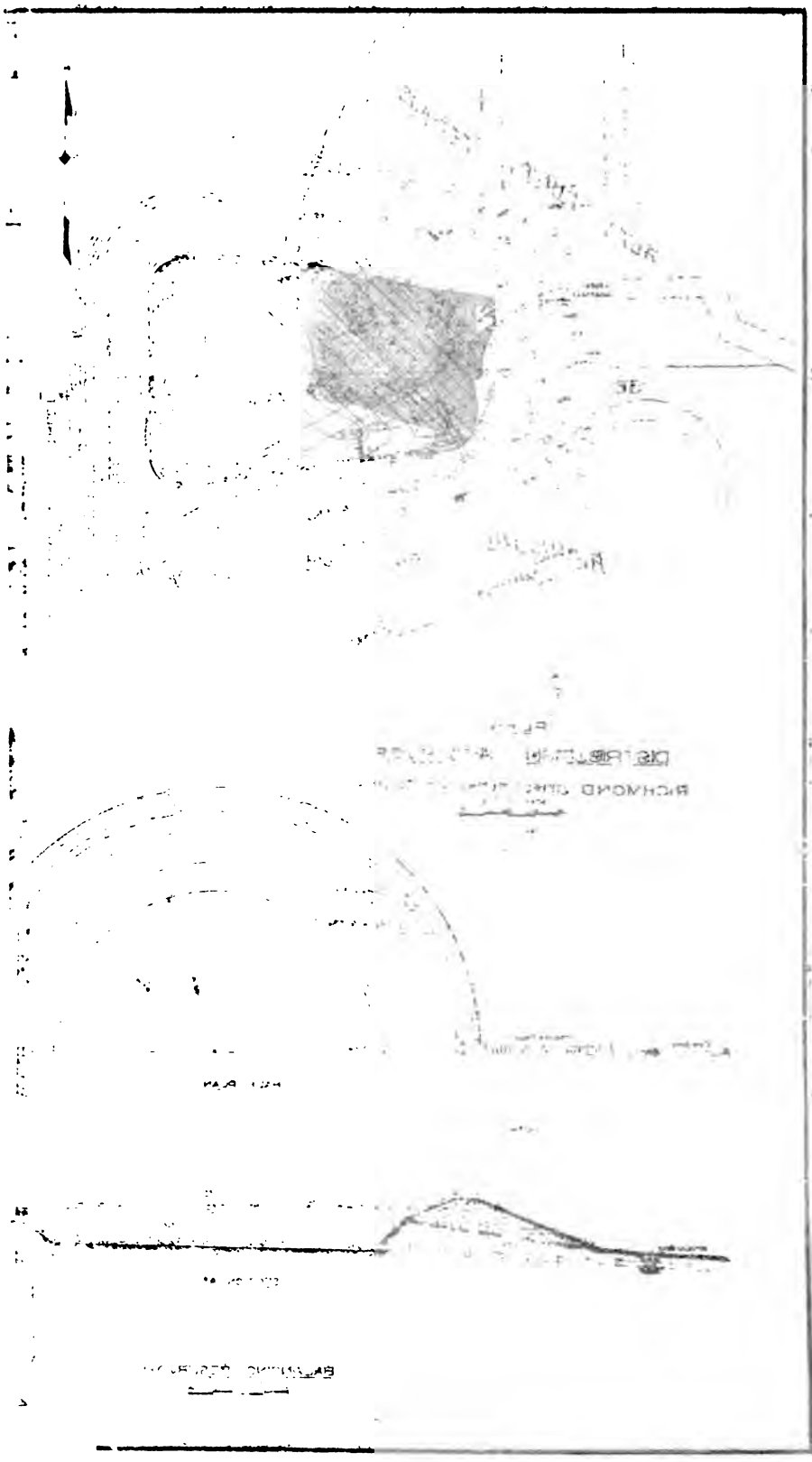


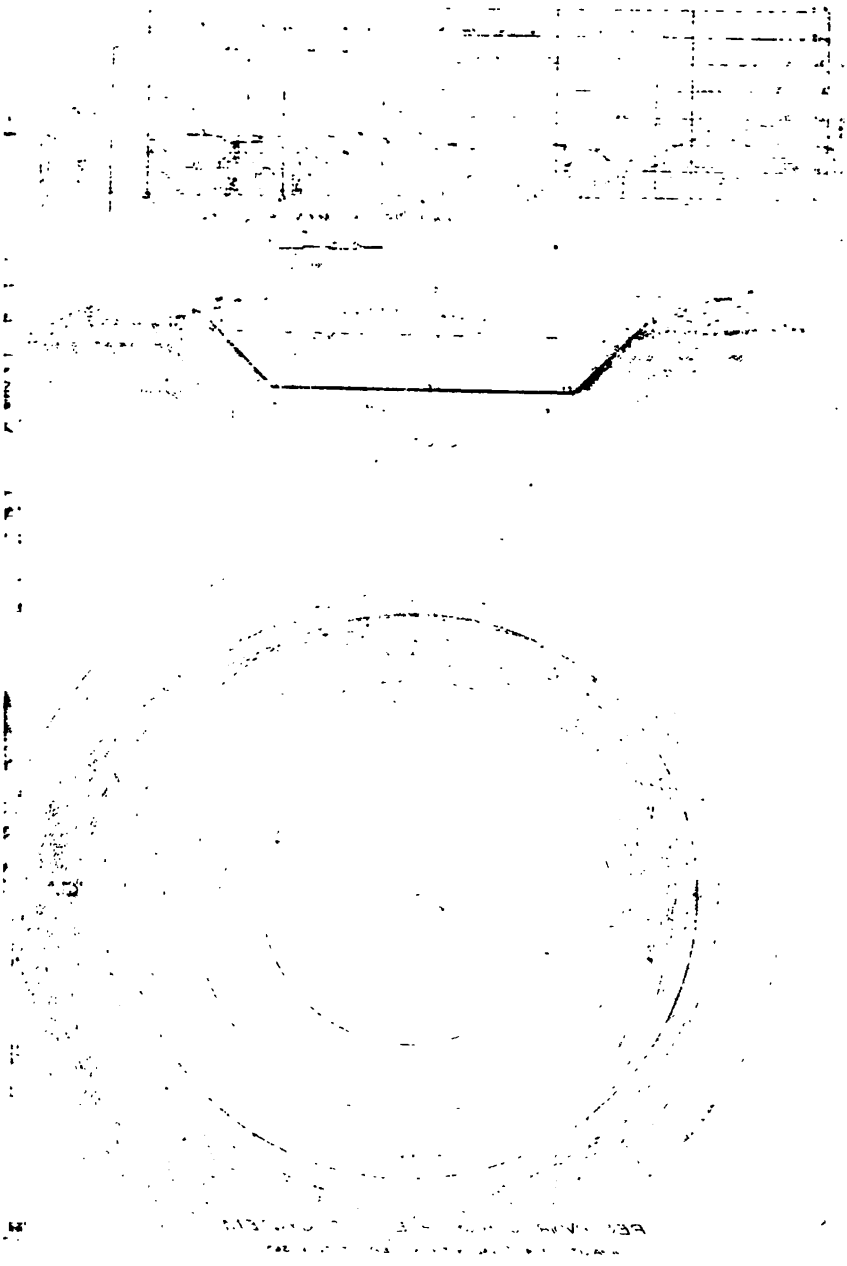


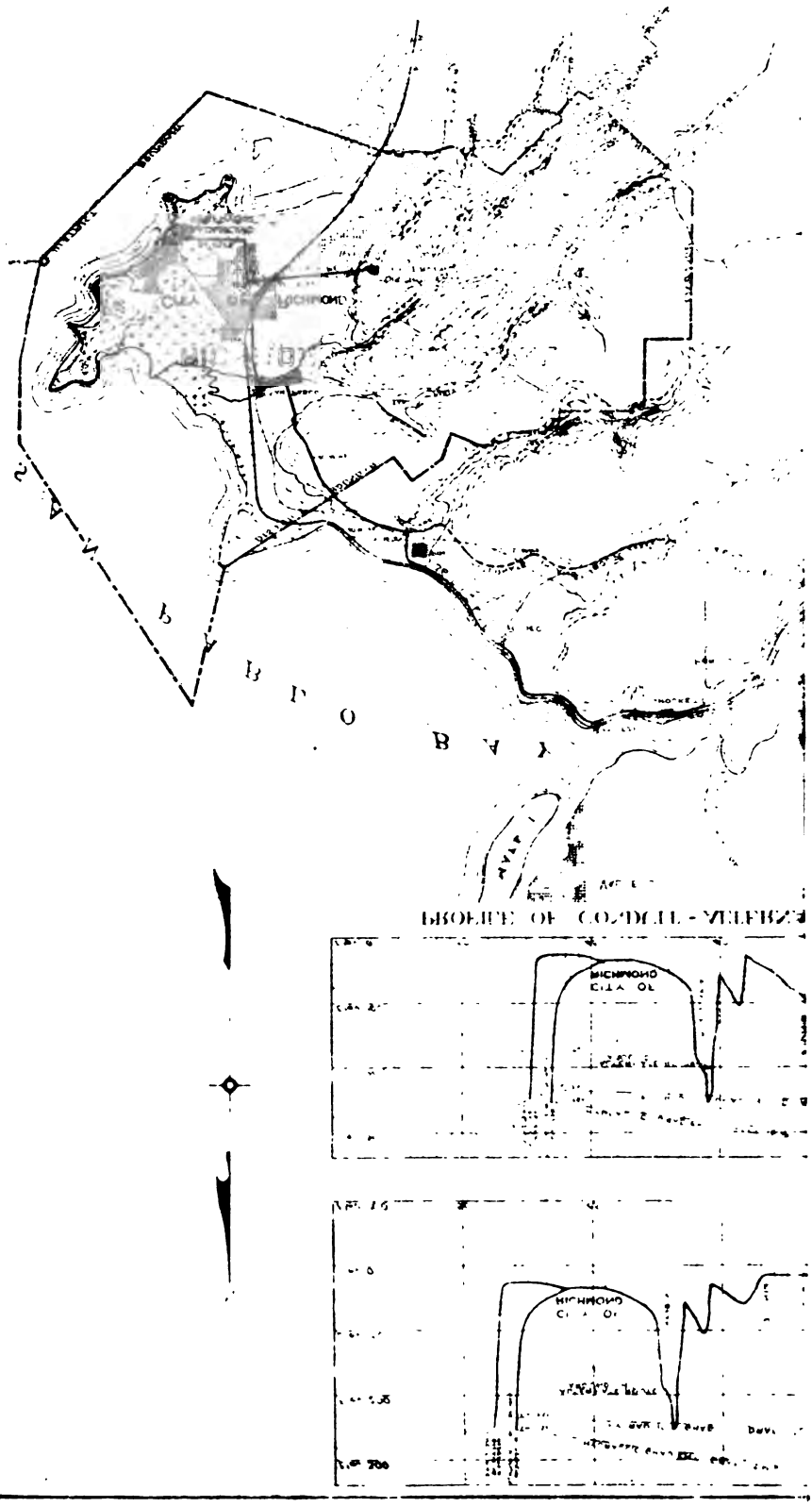












SACRAMENTO RIVER
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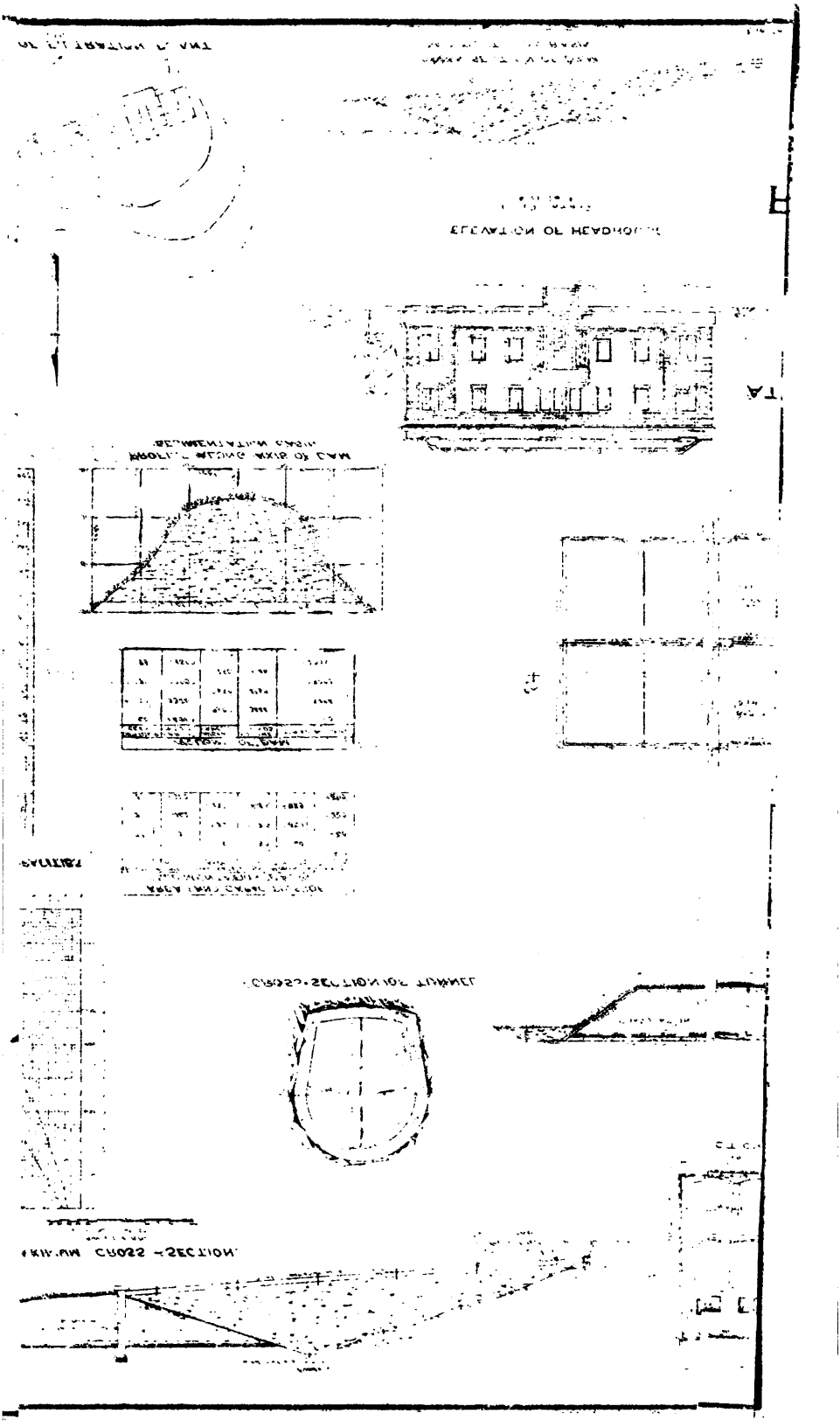

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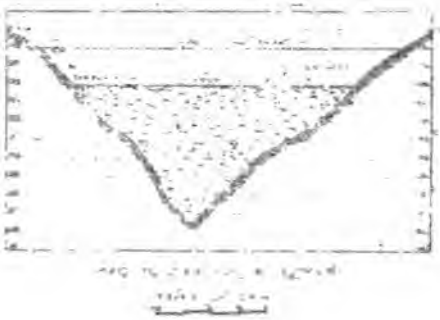

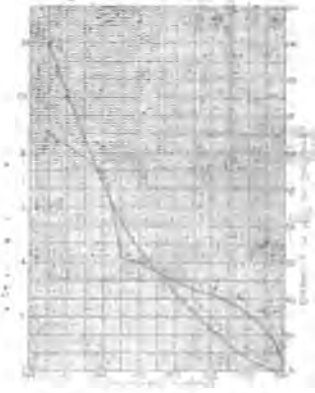

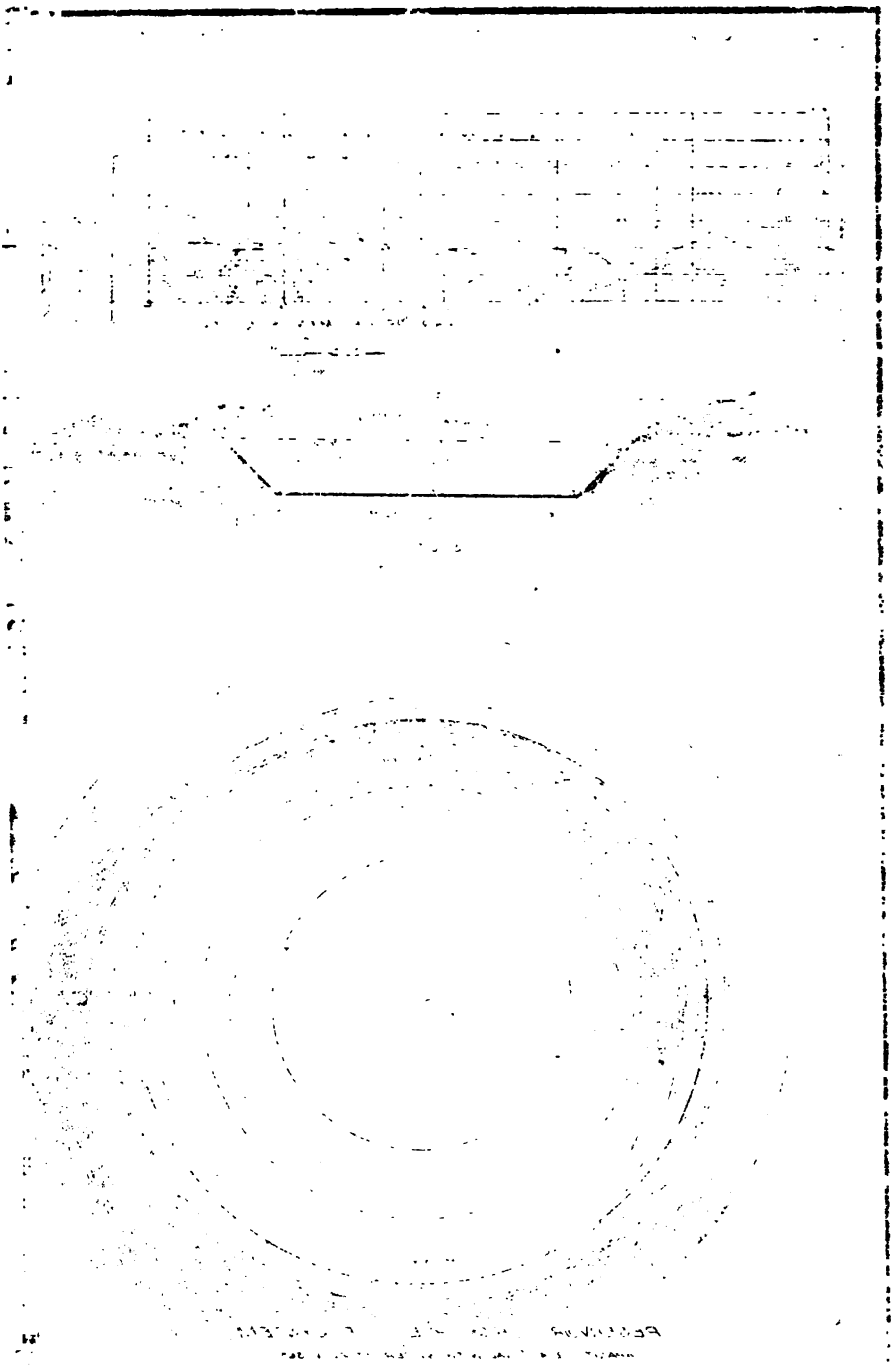

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